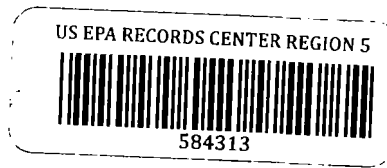


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AN INVESTIGATION OF A VOLATILE ORGANIC CHEMICAL PLUME IN NORTHERN WINNEBAGO COUNTY, ILLINOIS

Document No. 84/09



ENR

Illinois Department of
Energy and Natural Resources

James R. Thompson, Governor
Michael B. Witte, Director

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SWS Contract Report 346
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AN INVESTIGATION OF A VOLATILE ORGANIC CHEMICAL PLUME
IN NORTHERN WINNEBAGO COUNTY, ILLINOIS

by

H. Allen Wehrmann

Project No. 83/4001

James R. Thompson, Governor
State of Illinois

Michael B. Witte, Director
Department of Energy and
Natural Resources

Prepared under contract with the Illinois Department of Energy
and Natural Resources as project number 83/4001; from the
State Water Survey Division, Champaign, Illinois

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ABSTRACT

Subsequent to a one year investigation of groundwater nitrate quality near Roscoe, a small community in north-central Illinois, the Winnebago County Public Health Department instituted a sampling effort to examine for the presence of organic constituents. An initial sampling of five homes in January and February 1983 found concentrations of total volatile organic chemicals (VOCs) ranging from 60 to over 1000 $\mu\text{g/L}$. The principal component found in all the samples was trichloroethylene, TCE, a widely used industrial solvent. Through the following year the Illinois State Water Survey, working with the County and State Health Departments and the State Environmental Protection Agency, conducted a study to delineate the extent and movement of the VOC plume and to estimate the exposure to VOCs that local residents may have received from their private drinking water supplies.

Beneath two residential areas, Hononegah Country Estates and Moore Haven Subdivisions, the plume has spread to approximately 1200 feet in width, affecting nearly 100 homes. TCE concentrations range from trace amounts along the western edge of the plume to over 1500 $\mu\text{g/L}$ along the central axis of the plume. The plume closely follows the natural groundwater gradient from north-northeast to south-southwest. The plume is approximately 6000 feet long, originating in the vicinity of a local manufacturer, and terminating at a natural discharge area, the Rock River. Hydraulic conductivity testing and mapping of groundwater elevation contours indicate the rate of groundwater movement is approximately 1 foot per day.

Computer simulation of the contaminant movement allowed calculation of expected exposures through drinking water by residents living in the affected subdivisions. Due to the lack of data available to identify a time-frame for source origination, two scenarios were employed to bracket a range of possible TCE doses that the residents may have ingested. A TCE dose was determined by calculating the area under a simulated curve of TCE concentration versus time for a given location within the plume and then multiplying the area by an estimate of an individual's water intake. In the "least" case scenario, the leading edge of the plume was assumed to have reached the Rock River in early 1983. A "worst" case scenario assumed the plume has been discharging to the Rock River long enough such that recently observed TCE concentrations were also present when the homes were built (approximately 10 years ago).

The discovery of this organic plume was fortunate. If the County Health Department had not taken the initiative to sample the groundwater for organics, those contaminants may still be undetected and many people would be continuing to drink potentially harmful water unknowingly. The manner in which this plume was discovered is just one example of the need for routine sampling of private wells throughout the state, particularly in locations downgradient of potential groundwater contamination sources.

ACKNOWLEDGMENTS

This project was funded by the Department of Energy and Natural Resources, under the directorship of Michael B. Witte, as an amendment to project number 83/4001, "Hazardous Wastes in Illinois: Identification and Prioritization of Past and Present Activities as Related to Potential Risk." Tim Warren was the Project Manager and reviewed the draft reports. As a project encompassing the concerns of several governmental agencies, acknowledgment must be given to the contributions of the Illinois Environmental Protection Agency, the State Department of Public Health, the Winnebago County Public Health Department, the Sanitary District of Rockford, and the University of Illinois' School of Medicine at Rockford.

In particular, I wish to extend my sincerest appreciation for the cooperation, encouragement, and friendship extended by Mr. Maichle Bacon, Director of Environmental Health, Winnebago County Public Health Department, and Mr. Roger Ruden, Regional Engineer, State Department of Public Health. It was only through Mike's initiative in confronting this environmental problem that the project came to fruition. I am also indebted to the respective staffs of Mike's and Roger's for their helpfulness in collecting the many water samples that were taken during the investigation. I also would like to thank Dr. Dietmar Grohlich, Division of Laboratories, Toxicology, State Department of Public Health, Chicago, for his singular perseverance in analyzing those water samples and for his contribution to the report describing the technical aspects of gas chromatography/mass spectrophotometry.

Several members of the State Environmental Protection Agency lent their time and effort. These include Robert Wengrow, Rockford Regional Head of the Division of Land Pollution Control; Sherri Otto, who coordinated the

driller's availability; Timothy Greetis, geologist; Douglas Tolan, driller; and Steven Estes, driller's assistant. Their assistance and helpfulness during the drilling operation in particular is greatly appreciated.

The project was conducted under the general supervision of Stanley A. Changnon, Jr., Chief of the Illinois State Water Survey. James Gibb, Head of the Groundwater Section, lent his support and guidance through the course of the project and reviewed the draft reports. Dr. Michael Barcelona, Head of the Aquatic Chemistry Section, provided comments concerning the sampling and analysis of organics and reviewed portions of the report. Dr. Thomas Naymik, former Hydrologist at the Survey, started my experience with the solute transport computer model. Further support was lent by Michael Broten, Joseph Ritchey, and Mark Collins with their availability and technical support during the modeling phase and assistance with the computer graphics. Mark Sievers contributed several days helping collect water samples and assisting with the topographic survey. John Brother, Linda Riggin, and William "Bud" Motherway prepared the graphic displays within the report and Kathleen Brown and Pamela Lovett typed the drafts and final manuscript. My thanks to all for their support.

Lastly, I wish to thank the many Rockford area drillers for contributing their time, hard labor, and patience (without reimbursement) during several hot July days while we constructed and sampled the preliminary monitoring wells. At the risk of forgetting to mention all those who contributed, I wish to personally thank Jerry Rosenquist, Ed Greenfield, Jim Hinkle, Bob Olson, Melvin "Red" McKinney, and Jesse Beamon. The help of these men and others signifies the concern local residents and businessmen have over their precious groundwater resource.

INTRODUCTION

Background

Located in extreme north-central Illinois, hundreds of homes have been built on the sandy terraces of the Rock River in Winnebago County. In the areas near the Village of Roscoe, most homes use individual well and septic systems for water supply and wastewater disposal. A one-year investigation by the Illinois State Water Survey found that because the sandy soils have an extremely low capacity for attenuating the nitrate load being discharged by the large number of densely situated septic systems in the area, more strict control of future housing density must be used to maintain acceptable groundwater quality.¹

All groundwater quality analyses performed during that study were for inorganic constituents in the water. Knowing the potential for domestic wastewaters to contain harmful organic chemicals, some of which have been associated with septic system "additives,"² and the close association between septic system discharge and groundwater quality in this area, it was felt that the groundwater might also contain organic compounds.

During the winter of 1983, the Winnebago County Public Health Department instituted a sampling effort to examine for organics in the groundwater of the Roscoe area. Five homes in the Hononegah Country Estates Subdivision were targeted for an initial sampling. The results were startling (see Table 1). All five samples contained organic constituents ranging from approximately 60 to over 1000 micrograms/liter ($\mu\text{g/L}$ or parts-per-billion, ppb) total volatile organic chemicals (VOCs). The principal component found in all the samples was trichloroethylene, TCE, a widely used industrial solvent. Among the other organic compounds found in relatively minor amounts were trans 1,2,-dichloroethylene, 1,1,1-trichloroethane, and tetrachloroethane.

Table 1. Results of Initial Sampling for VOCs in the Hononegah Country Estates Subdivision

Well I.D.	Date sampled	Volatile Organic Chemical Concentration (µg/L)					
		TCE	a*	b*	c*	d*	e*
HS6040	2/09/83	54	8	2	-	-	-
HS6074	1/28/83	726	-	-	-	-	-
HS6075	2/09/83	964	64	24	2	3	1
HS6076	2/09/83	280	9	3	-	-	-
HS6077	2/09/83	417	6	5	-	-	-

*a: trans 1,2-dichloroethylene; b: 1,1,1-trichloroethane;
c: 1,1-dichloroethylene; d: tetrachloroethane; e: 1,2-dichloropropane

By March, a broader based sampling program had been initiated by the County Health Department with the assistance of the State Department of Public Health to try to identify the extent of the contaminated area. Illinois State Environmental Protection Agency personnel also canvassed local industries to determine the usage of organic chemicals in the area.

From the data gathered through April, it became apparent that the organic contaminant plume was not confined within Hononegah Country Estates. While water samples collected within the extreme western portion of Hononegah Country Estates found only minute amounts of organics (up to 3 µg/L total VOCs), water collected from wells northeast of the subdivision during the IEPA sampling found from trace amounts to over 100 µg/L total VOCs. One manufacturer was found to use TCE to degrease parts; a sampling of their industrial wastewater effluent contained approximately 600 µg/L total VOCs.

The presence of organic compounds in the groundwater presented several important questions:

- 1) What was the source of the contaminants?
- 2) What was the extent of the contamination?
- 3) How long had the contamination been present in local wells?
- 4) Could any health effects be associated to exposure through drinking water by the local residents?

The health aspect was an obvious concern to the County and State Health Departments. Research has linked TCE exposure to cancer in laboratory mice³ but the question remains on how accurately extrapolations from laboratory animal experiments can predict carcinogenicity in humans.^{4,5} However, "risk extrapolation is generally recognized as the only tool available at this time for estimating the magnitude of potential health risks associated with non-threshold toxicants and has been endorsed by numerous federal agencies and scientific organizations, including EPA's Carcinogen Assessment Group, and the National Academy of Sciences Safe Drinking Water Committee."⁶

The National Academy of Sciences (NAS) and EPA's Carcinogen Assessment Group (CAG) have developed cancer risk models to calculate concentrations for which increased cancer risks could occur if consumed over a 70 year lifetime at two liters per day. Table 2 presents the projected increase of lifetime cancer risks from consumption of TCE predicted by the two models.⁶ Concentrations of TCE found at several wells within Hononegah Country Estates were in excess of the range exhibited for an increased risk of one in ten thousand (for 70 year lifetime exposure).

Table 2. Projected Increase in Cancer Risk Due to
Lifetime Exposure to Trichloroethylene*

TCE Concentrations in drinking water (µg/L)		Projected excess lifetime cancer risk (one case per described population size)
CAG model	NAS model	
2.8	4.5	1 in 1,000,000
28	45	1 in 100,000
280	450	1 in 10,000

*From March 4, 1982 Federal Register

To understand the complexity of this situation, of the thousands of organic compounds in existence, only a few have established drinking water standards. Recommended Maximum Contaminant Levels (RMCLs) for TCE and 1,1-dichloroethylene have been recently proposed at the zero level.⁷ RMCLs are non-enforceable health goals and are set at "levels which would result in no known or anticipated adverse health effects with an adequate margin of safety."⁸ In the face of the potential health risks associated with cancer-causing toxicants, where no safe threshold can be demonstrated, an RMCL of zero is advised. However, "RMCLs of themselves have no impact on public water systems or the public...[They] serve as goals for the Agency [U.S.E.P.A.] in the course of setting MCLs..."⁷ Maximum Contaminant Levels (MCLs) are enforceable standards set as close to the RMCLs as feasible, based upon health, treatment technologies, cost, and other factors. Indications are that the MCLs for TCE and several other VOCs will be in the 5 to 50 µg/L range.⁷

Because of the lack of available data on long-term exposures to TCE in drinking water, the Winnebago County Health Department (with the University of Illinois' College of Medicine in Rockford and the Illinois Department of Public Health) proposed to the Illinois Department of Energy and Natural Resources to conduct an epidemiological investigation of residents exposed to the contaminated water. The primary purposes of the investigation were to 1) measure the possible health effects of exposure to the mixture of toxic organic chemicals found in the drinking water and 2) examine the relationship of measurable health effects and the degree of exposure. That project was funded in June, 1983.

Scope of Work

DENR also funded the Illinois State Water Survey to provide information on the degree to which residents had been exposed as input to the epidemiological study. This information includes an estimate of the length of time of exposure as well as the concentrations experienced during exposure. More specifically, information was needed which could:

- a) Describe the VOC contaminant plume geometry, concentrations of VOCs, locations, and depths,
- b) Define the source of the plume,
- c) Describe the movement of the plume, and
- d) Provide an estimate of the exposure to VOCs that local residents have received from their drinking water.

Study Area Description

The study area encompasses approximately one square mile located near the Rock River in northern Winnebago County (figure 1). Much of the investigation centered on the Hononegah Country Estates and Moore Haven

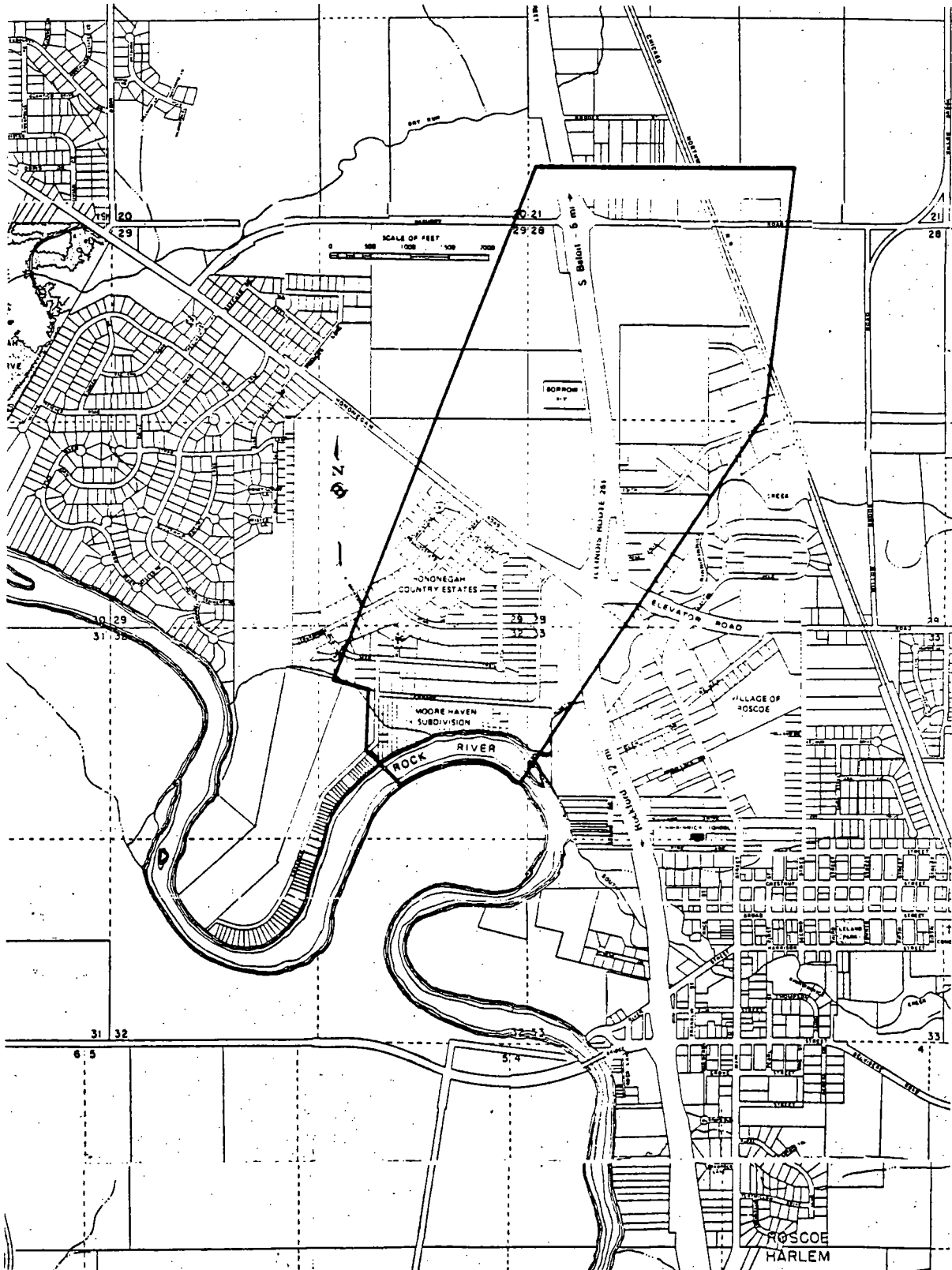


Figure 1. Area of investigation.

Subdivisions situated in the southern part of the study area along the Rock River (SE 1/4, Section 29 and NE 1/4, Section 32, Township 46 North, Range 2 East).

No centralized water or sewer systems have been built within the study area. Each home, farm, and business maintains a private, on-site water well and wastewater treatment system. The large number of wells supplying the homes in the subdivisions provided an excellent means of sampling groundwater in a fairly dense array over a 1/4 square mile area. The affected area within the subdivisions contains approximately 180 lots, 120 to 130 of which are occupied. Therefore, there are potentially more than 130 wells (including commercially owned wells) serving more than 400 people within the study area. Based on knowledge about groundwater flow direction from previous work¹ and organic sampling results, the study area was expanded in a general northeastward direction.

Most of the study area is situated on a broad, flat terrace overlooking the floodplain of the Rock River. The land surface elevation ranges from approximately 750 feet above mean sea level to 710 feet along the Rock River. A perennial stream, North Kinnikinnick Creek, traverses the southeastern boundary of the study area.

The study area consists principally of farmed acreage and formerly farmed land which was subdivided into residential housing. Moore Haven Subdivision is situated along the Rock River south of Edgemere Terrace; many of the homes in Moore Haven have been occupied 15 years or longer. Hononegah Country Estates Subdivision is a much younger development with zoning approval for residential housing occurring in 1974. Many of the homeowners

in this subdivision have lived there only 5 to 7 years. The population is composed primarily of young families with a fair mix of blue- and white-collar workers.

The eastern and northern sectors of the study area are occupied by commercial and industrial enterprises. Two industries, a quarry located on 112 acres near the southwest corner of Route 251 and McCurry Road and a manufacturer for the auto and business machine industry, located on 94 acres at the southeast corner of Route 251 and McCurry Road, occupy the largest area and are located near the northern boundary of the study area.

GEOLOGY AND HYDROLOGY

Geology of the Roscoe Area

The geology of Winnebago County has been extensively studied and interpreted.^{8,9,10} Beneath the study area, the bedrock surface has been carved into a deep valley. This valley, which underlies the modern Rock River Valley, was formed centuries ago by the erosion of flowing water during the advance and retreat of several continental glaciers. As the last glaciers retreated northward, glacial meltwaters washed huge amounts of debris (silt, clay, sand, gravel, and organic materials) into the valley. Much of the sediment that filled the valley in the Roscoe area is sand and gravel, as much as 250 feet thick in the deepest portions of the now buried bedrock valley. A cross section through the study area, prepared by the State Geological Survey,¹⁰ is shown in figure 2.

The bedrock valley was carved through the Galena-Platteville Dolomite to expose the underlying St. Peter Sandstone. The bedrock surface rises sharply to the east and west forming a sharp boundary to the central valley. Well-drained sand and gravel terraces formed by the cutting of the valley deposits and subsequent refilling with lesser amounts of glacial debris is topographically evident.

Groundwater Occurrence and Movement

Figure 3 portrays an idealized picture of the hydrologic cycle for the study area. Water condensed in the atmosphere falls as precipitation. Most of the water is evaporated back to the atmosphere or flows overland to local streams and rivers. A smaller portion percolates downward through the pore

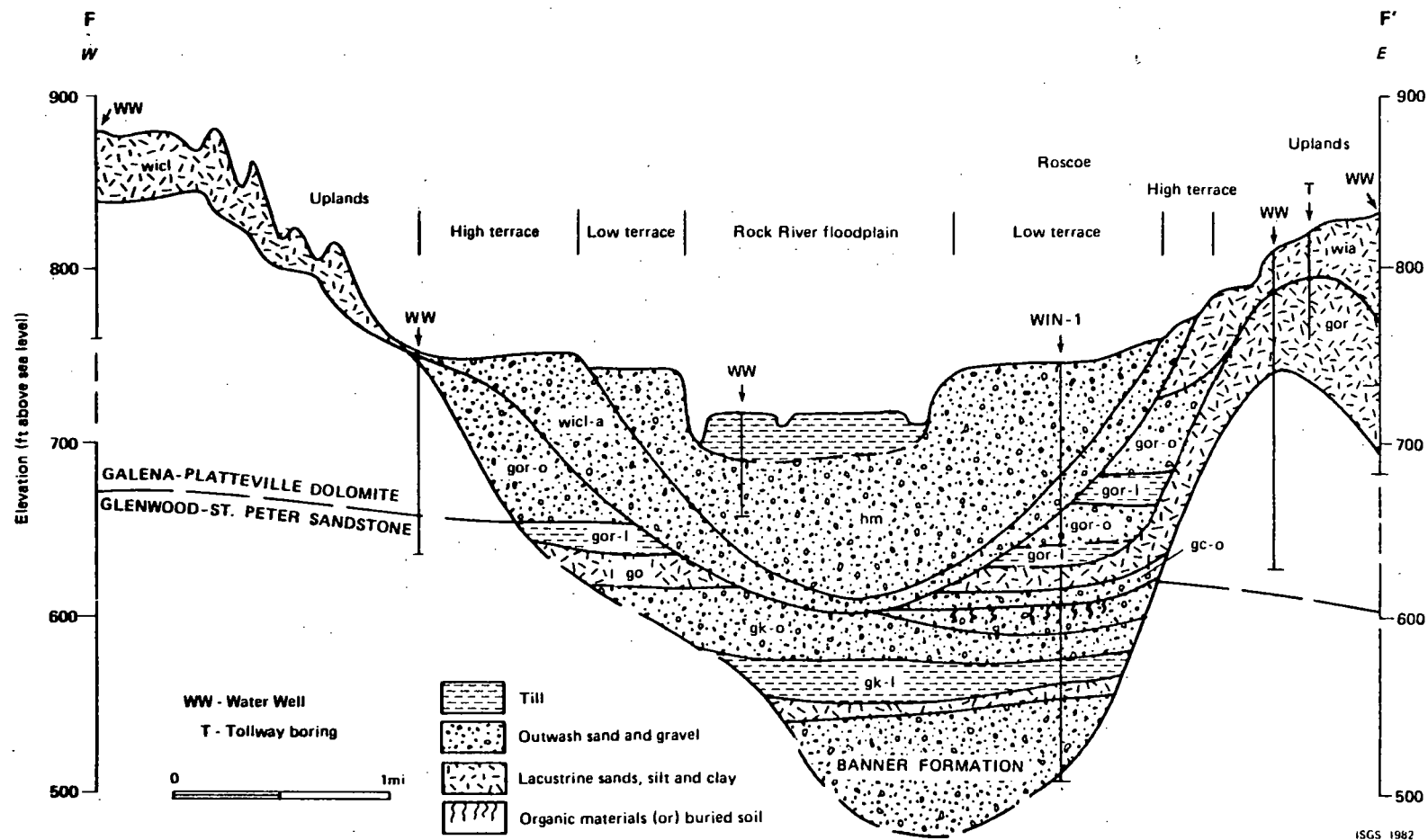


Figure 2. West to east cross section across Rock River Valley at Roscoe (from Berg et al., 1981).

spaces of the soil under the influence of gravity. Water in the near surface soils is available to plant roots and can be transpired back to the atmosphere.

The amount of water which infiltrates from a given storm is dependent upon the amount and intensity of precipitation, the slope of the land surface, the permeability of the soil (the amount of pore space open to the flow of water), the type and density of plant growth on the soil, and antecedent soil moisture conditions. The sandy soils throughout the study area can readily accept and transmit precipitation to deeper zones.

As the water moves downward, it reaches a point where all pore spaces are saturated. The surface of this zone of saturation is called the water table. The water table is a surface which can be approximated by the elevation of water surfaces in wells which just penetrate the saturated zone. The vertical position of the water table will fluctuate in response to rainfall recharge, evapotranspiration, and groundwater withdrawals (pumpage).

In the study area, the water table can be found at depths from 30 to 40 feet. Under natural conditions, the water table forms a surface which resembles the overlying land surface topography only in a much more subdued and smoother configuration. The water table will be at higher elevations beneath upland areas and at lower elevations in valley bottoms. The water table may intersect the ground surface along perennial streams, springs, and lakes which are natural areas of groundwater discharge.

Groundwater discharge (or runoff) is a significant portion of the total flow present in a surface stream or river. The flow in a perennial stream after extended periods without precipitation is due, in large part, to groundwater discharge. For some streams in Illinois, as much as 90 percent of the streamflow during dry periods is from groundwater discharge. The

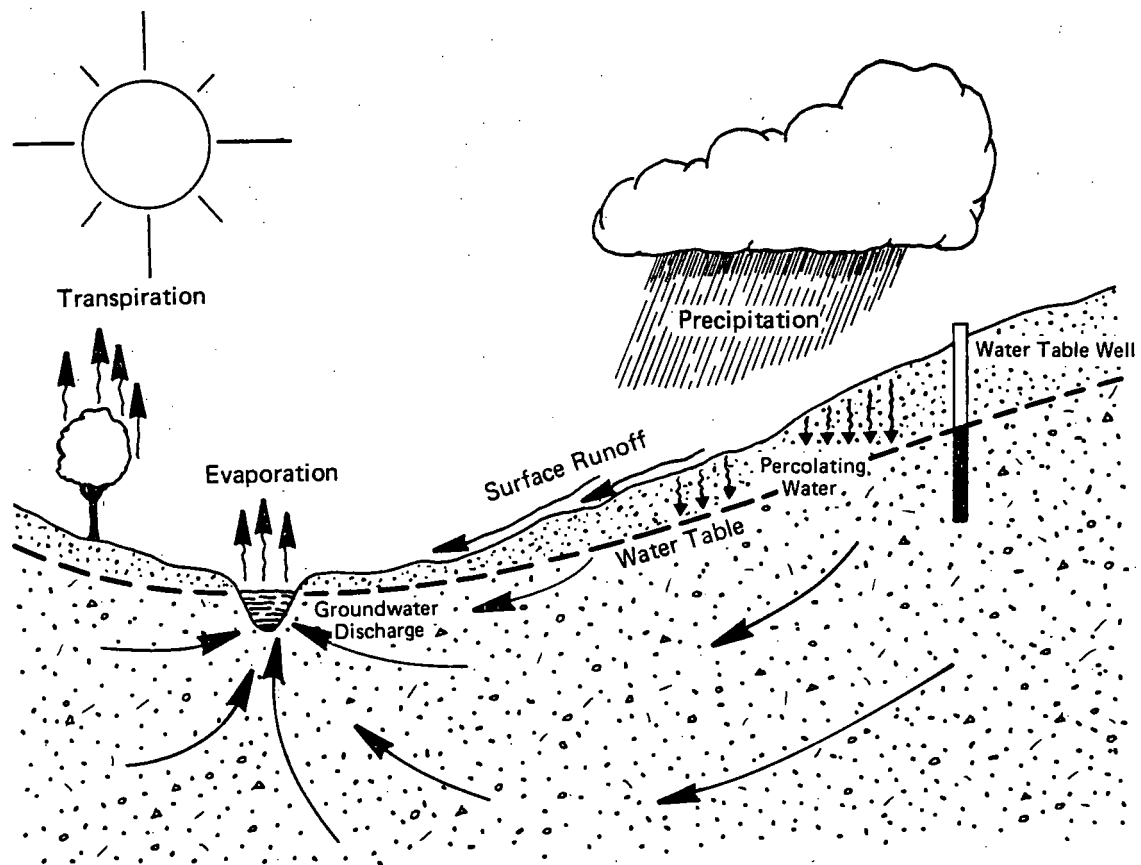


Figure 3. Generalized hydrologic cycle.

amount of water which discharges to a given stream is greatly dependent on the surrounding geology, topography, soil permeability, climatology, and land use.

Estimates of the magnitude of groundwater discharge have been made using streamflow hydrograph separation techniques. Because of the continuity of flow of groundwater, when averaged over long periods of time, groundwater recharge can be equated to groundwater discharge. Studies conducted at the Illinois State Water Survey^{11,12} for river basins similar to the area surrounding Roscoe show groundwater discharge to surface streams averages 142,000 to 237,000 gallons per day per square mile. These figures are equivalent to 3 to 5 inches of infiltrated precipitation per year (the annual precipitation for the study area is approximately 33 inches).

Groundwater moves in a fashion analogous to surface water. While surface water moves downhill in response to gravity, groundwater moves "downgradient" from areas of higher potential (or elevation) to areas of lower potential. The direction of groundwater movement, from high potential to low, can be determined by mapping the elevations of water levels in wells. Groundwater movement will be perpendicular to the contours of groundwater surface elevations. The rate of groundwater movement is related to the magnitude of the slope of the water table and the ability of the geologic materials to transmit water.

Groundwater in drift deposits, such as those beneath the study area, is directly recharged by percolation of precipitation occurring in the immediate vicinity. Generally, a potential exists for groundwater in the upper deposits to move vertically downward to recharge deeper deposits. However, because of the proximity to a major regional discharge point, the Rock River, the major component of movement will be laterally toward the river. While

some recharge of the deeper deposits is expected to occur within the study area, most of the recharge to those deposits occurs in areas more removed from the river. For the purposes of this investigation, only groundwater in the upper 100 feet of the glacial materials is considered. This system is only a part of the total groundwater flow system.

Groundwater Contamination

A wide variety of man's activities can lead to groundwater contamination. A constituent found in water may or may not be considered a contaminant depending on the intended use of the water. While groundwater is generally thought by the public to be "pure," most groundwater naturally contains dissolved minerals which our bodies can use and may actually need. However, recent advances in analytical technology have allowed the discovery of very small quantities of dissolved constituents, many potentially harmful to human health, that originate from previously unrecognized sources.

Table 3 lists a number of potential groundwater contamination sources. While many are waste-related, a substantial number of sources involve the storage or transport of raw materials that are not "wastes" until found in a water supply. Contaminant releases can occur by design or by accident or neglect.

The potential for an aquifer to become contaminated can become enhanced by the direct connection of the aquifer to these sources through poorly constructed wells or wells which have not been properly abandoned when no longer used. Most contamination incidents involve materials released at or only slightly below the land surface. Therefore, it is the shallow groundwater which is normally most susceptible. The mechanism by which groundwater

Table 3. Potential Sources of Groundwater Contamination

Waste-Related Activities

- Individual sewage systems (septic tank-leach field, cesspools, etc.)
- Municipal landfills
- Hazardous waste landfills
- Liquid waste & sludge disposal (rapid infiltration treatment, etc.)
- Treatment lagoons and ponds
- Tailings ponds & other mine-related activities
- Animal feed lots
- Deep well injection

Chemical Application

- Fertilizers
- Pesticides
- Highway de-icing
- Waste water irrigation

Chemical Storage

- Gas stations
- Salt piles
- Natural gas storage
- Coal piles
- Industrial materials storage

Transmission

- Pipelines
- Sewers
- Transportation accidents (train, truck, airplane, ship)
- Chemical loading and unloading areas

Aquifer cross-connections

- Poorly abandoned wells
- Multi-aquifer development
- Intra-aquifer gradient changes (i.e., from well development)

becomes contaminated is similar in many cases. Material that has leaked, spilled, or been disposed of is dissolved by precipitation and carried downward through the unsaturated zone to the water table (see figure 4).

Movement through the unsaturated zone is vertical, under the influence of gravity, with little lateral spreading. Horizontal movement does not generally occur until the water table is reached. When leakage occurs at a faster rate than the formation can accept, a groundwater mound is formed. Contaminants then spread outward in a radial pattern until an area capable of receiving the solute-pollutant load is affected.

The direction and extent of contaminant migration depends on several interrelated factors. Some of the main considerations are:

- 1) the direction of groundwater movement (which is related to the slope of the groundwater surface) and the position within the regional flow pattern (i.e., a recharge zone would mean groundwater is moving downward vs. a discharge zone where groundwater is moving upward),
- 2) the rate of groundwater movement (which is related to the magnitude of the slope of the groundwater surface and the hydraulic conductivity, or permeability, of the geologic formation),
- 3) the geohydrologic properties of the water-bearing formation, particularly inhomogeneities, fractures, faults, etc.,
- 4) the rate of contaminant leaching into the groundwater relative to the rate of groundwater flow beneath the source, and
- 5) the chemical and biological characteristics of the geologic materials and native groundwater relative to the released contaminant (physical/chemical processes, biodegradation, decay, dilution).

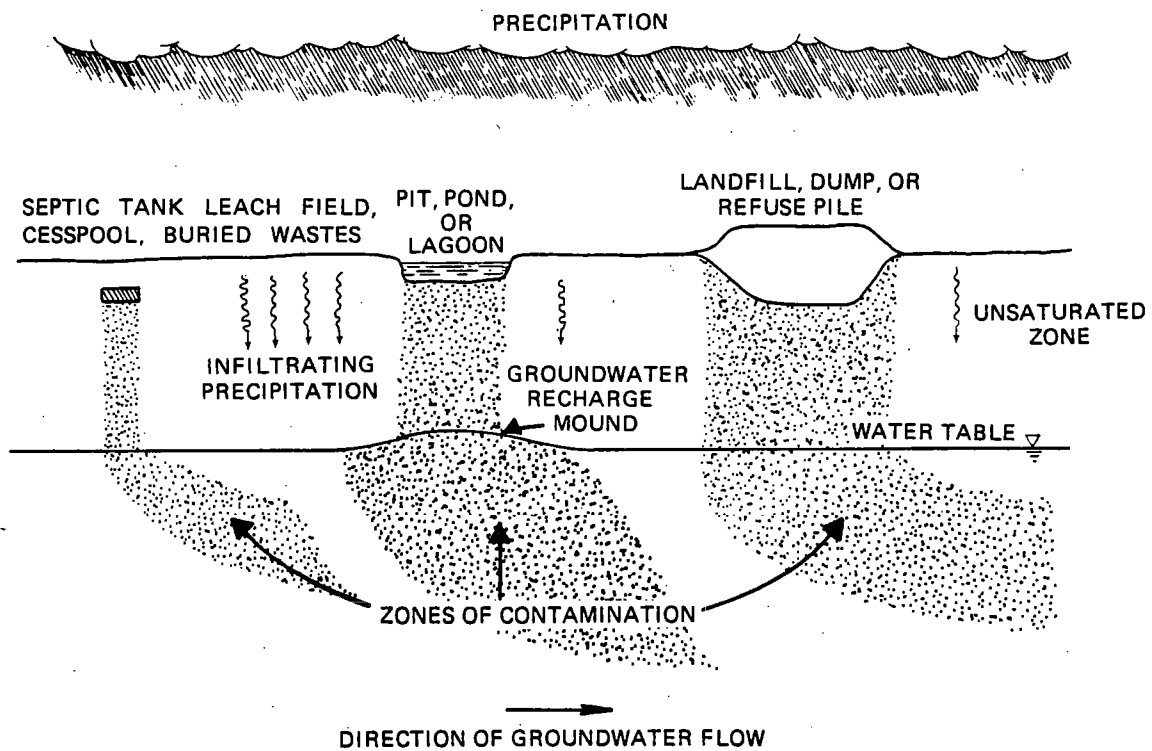


Figure 4. Aspects of groundwater contamination.

Once the water table is reached, contaminants entering the groundwater will move with the flow of the groundwater. This process is termed advection. The area or zone of contaminated water has been called an enclave or "plume" (figure 5) and is very similar in concept to a plume of smoke as it enters the atmosphere from a "smokestack" source. However, because groundwater movement is quite slow (often less than one foot per day), mixing of contaminated and uncontaminated water does not occur rapidly and contamination plumes are usually localized in nature. However, plumes have been discerned over hundreds to thousands of feet.^{13,14}

The area of greatest contaminant concentration is generally near the source with decreasing concentrations in the downgradient direction as dilution with uncontaminated water occurs. The mixing process, whereby a contaminant gradually spreads to occupy an increasing portion of the flow region, is known as dispersion. Dispersion takes place on two levels, macroscopic and microscopic (figure 6).¹⁵ Large-scale changes in the physical/hydraulic characteristics of the water-bearing formation can alter the groundwater flow pattern. For example, a clay lense within a sand and gravel aquifer will inhibit groundwater flow and distort movement around it (figure 6a). Movement will occur within the clay, however at a greatly reduced rate. On a microscopic scale, groundwater flow is affected by the size, distribution, and orientation of the pore spaces through which flow occurs (figure 6b). While the physical and chemical processes are more complex than illustrated, contaminant particles can be caused to spread both in the direction of flow (longitudinal dispersion) and perpendicular to the direction of flow (transverse dispersion).

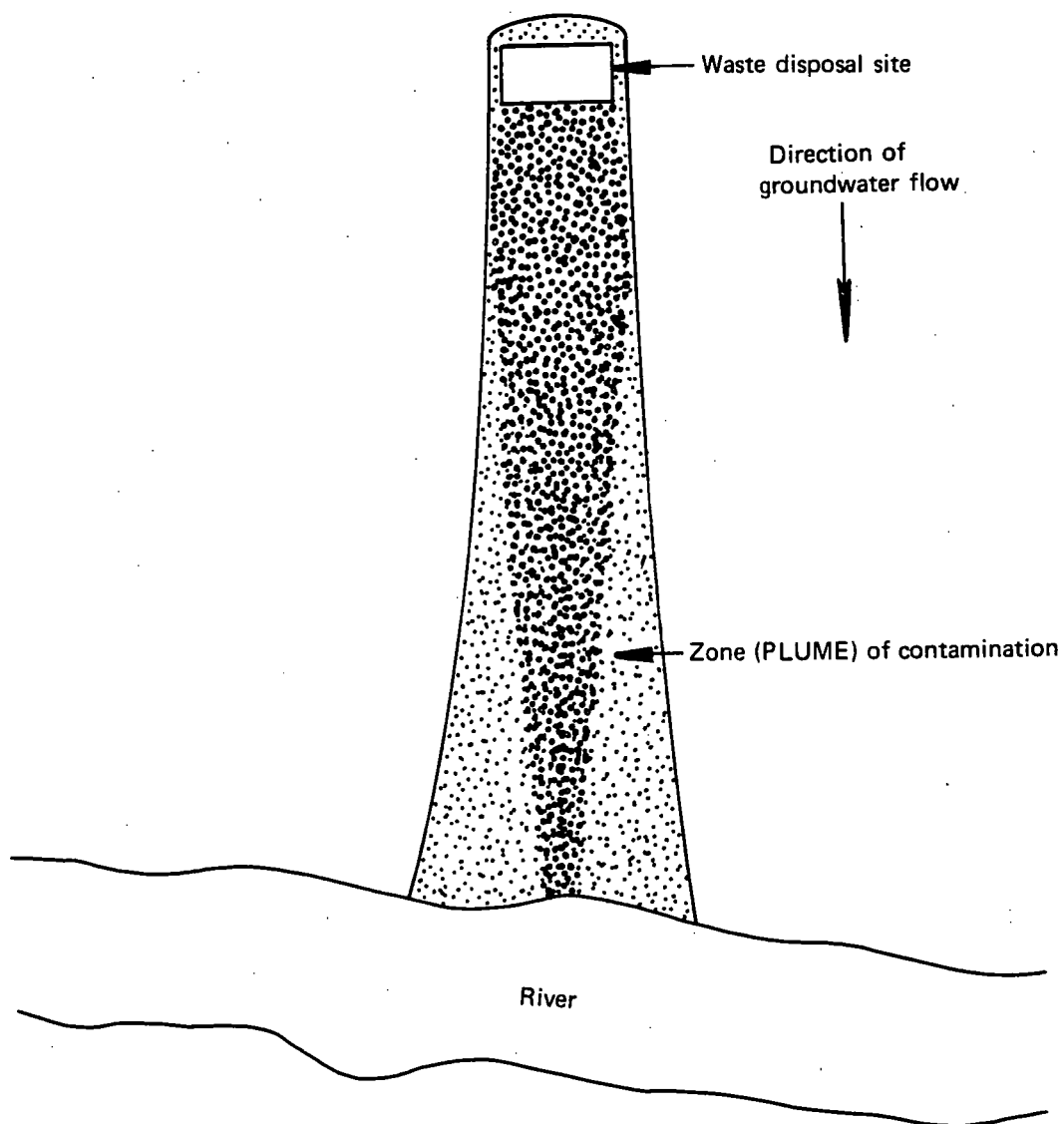
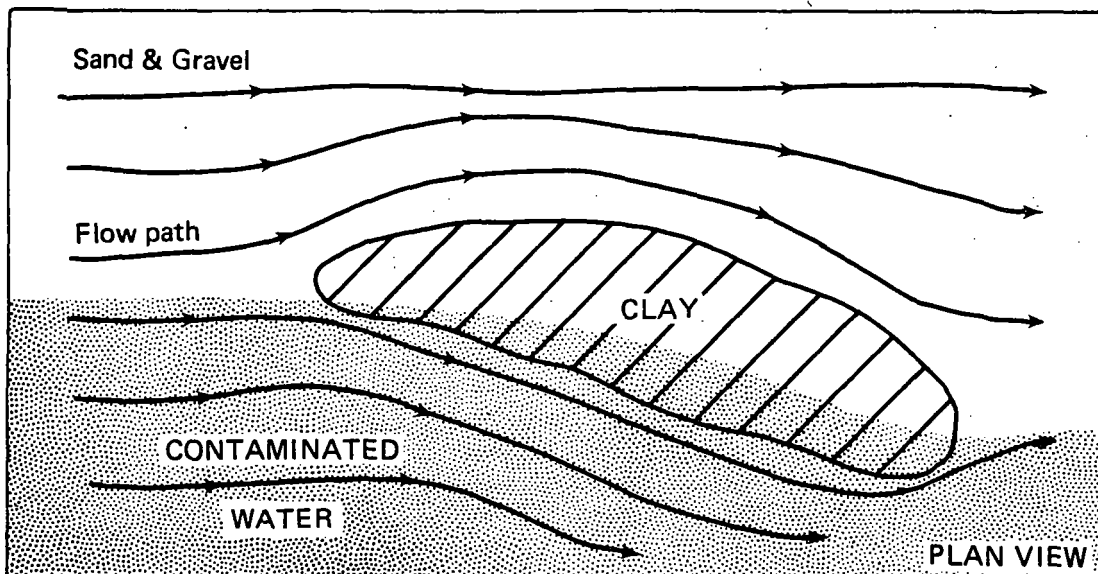


Figure 5. Plan view of an idealized groundwater contamination plume.

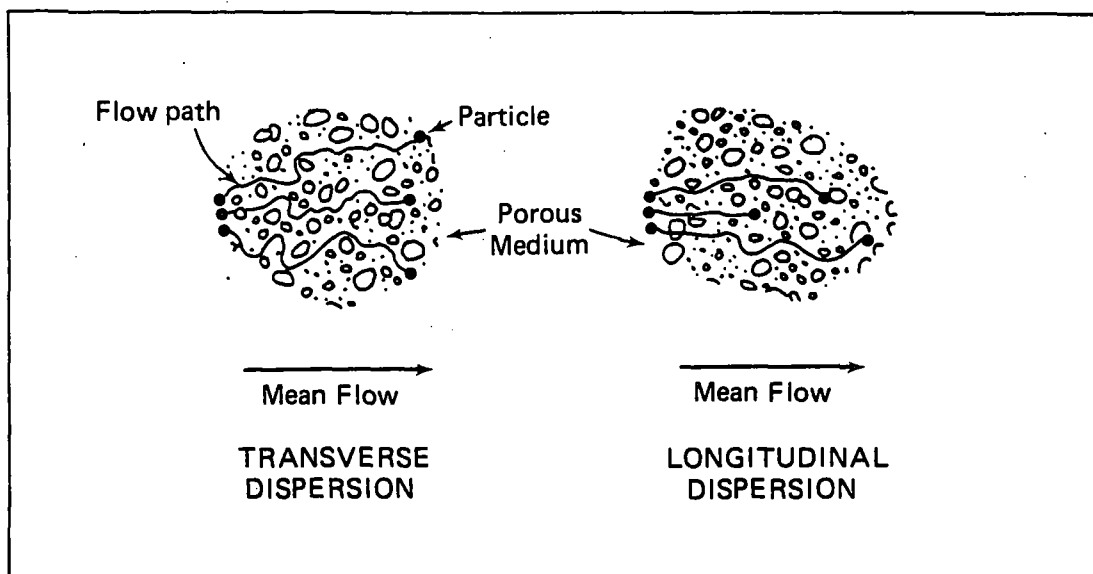
Groundwater contaminant movement is relatively slow and allows for some response time if contamination is discovered early. Contaminant migration can then be managed through control of groundwater movement by hydraulic and physical methods. However, because the movement of groundwater is slow, clean-up of contamination is also slow. If contamination is not discovered early, contaminant migration may continue over large areas and can linger for many years. Tens of years may be required before natural processes can dilute, transform, or flush contaminants out of the groundwater system.

Geologic Susceptibility to Surface and Near-Surface Activities

As previously discussed, the materials underlying the study area are principally sands and gravels deposited centuries ago by glacial meltwaters. The permeable nature of the sand and gravel permits relatively rapid flow of water and provides high well yields. However, the hydraulic characteristics that make this deposit a good aquifer also make it susceptible to contamination from a variety of sources. Walker¹⁶ identified several areas in Illinois which have a high potential for contamination from surface-derived sources based primarily on areas known to yield large amounts of groundwater from shallow, unprotected aquifers ("unprotected" relates to the absence of overlying material of fine texture which would retard the movement of potential contaminants). The Rock River Valley in northern Winnebago County was clearly defined. Berg¹⁰ characterized the same area as being subject to contamination from the land burial of wastes, septic tank systems, and surface application of waste products and agricultural chemicals because of a low-cation exchange capacity, generally attributed to low clay and organic content, and high porosities and hydraulic conductivities (permeability).



a. Flow distortion on a macroscopic scale



b. Flow distortion on a microscopic scale

Figure 6. Groundwater dispersion mechanisms a) macroscopic and b) microscopic.

METHODS AND PROCEDURES

Temporary Sampling Wells

The first problem to be addressed in the study was the determination of the VOC source. Of immediate concern was whether or not the source was local (within the subdivision) or distant. Results from well water samples collected by the IEPA from the businesses along Route 251 indicated the source was not local. However, concentrations of TCE in those wells were approximately 100 µg/L or less, much lower than concentrations found within Hononegah Country Estates (Table 1). Previous work¹ had established that groundwater flow beneath the affected subdivision was north-northeast to south-southwest; therefore, an attempt was made to construct several "temporary" wells just north of Hononegah Country Estates to determine if organics were present.

This area is principally farmland and permanent monitoring well installations in the fields were not desirable. Permanent monitoring well locations and depths were to be planned based on results from sample analysis of the temporary wells. If no organics were found, a local source within the subdivision would be more likely. If organics were found, it was hoped that the central axis of the VOC plume could be determined.

Original plans called for driving a 2-inch diameter sandpoint to depths from 40 to 70 feet. Samples would be collected at 10-foot intervals as the point was driven. Once the 70 foot depth was reached, the sandpoint would be pulled, the hole properly abandoned, and the point driven at a new sampling site. The first hole was to be placed north of the most highly contaminated area, just north of Hononegah Road. Holes were to be placed successively in an upgradient direction proceeding across the field (see figure 7). Temporary wells also would be placed along Route 251 proceeding from south to

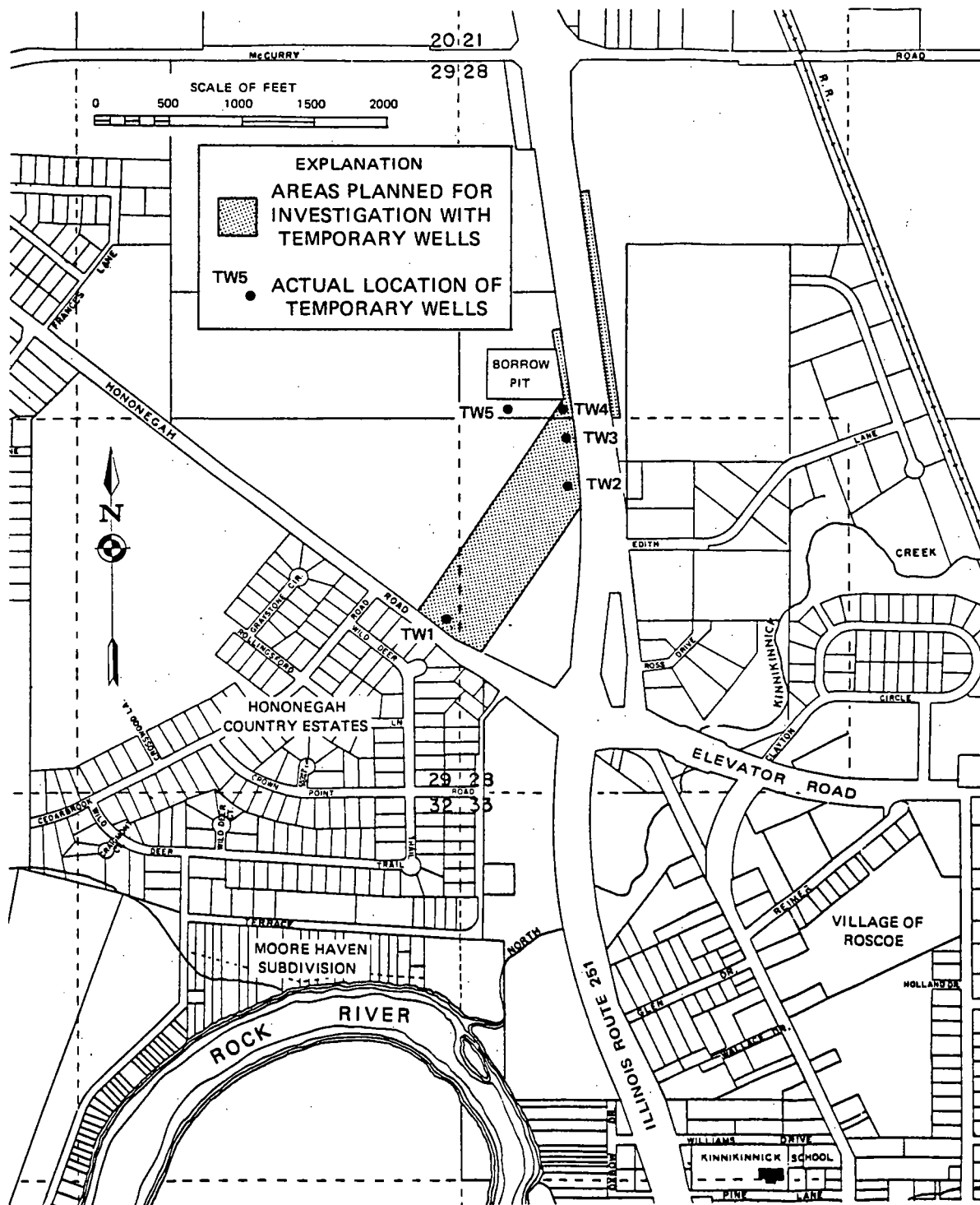


Figure 7. Areas contemplated for temporary well placement and locations of actual temporary well sites.

north at a spacing of 200 to 300 feet. In this manner, samples could be quickly collected at many depths and locations, the well materials recovered, and the area left relatively undisturbed for future use.

Drilling commenced on July 18, 1983 and it became obvious that the coarse sand and gravel near the land surface was too dense to permit the use of 2-inch diameter sandpoints. A larger drill rig was brought on-site and a new approach was used. A 4-inch diameter screen (2 feet long) with a drive shoe was welded to a 4-inch diameter steel casing. This assembly was driven by an air hammer attachment to the desired sampling depths. The bottom of the drive shoe was open allowing sand and gravel to enter the casing and screen. Before new sections of casing were welded to that already in the ground, the sand and gravel were evacuated from the casing and screen with an air-rotary bit. Due to the difficulties encountered with this procedure and the length of time required to penetrate the coarse geologic materials, only five holes, sampled at 40 and 50 feet, were completed. Locations of the temporary well sites are shown on figure 7. TW5 was situated to investigate the possibility that the borrow pit was the VOC source. To avoid cross-contamination by organics from using the same materials at several locations, all well and sampling materials were steam cleaned prior to use and between holes.

Permanent Monitoring Wells

Results from the temporary well sampling were used to plan the construction of nine permanent monitoring wells. Holes were drilled with the Illinois Environmental Protection Agency's hollow-stem auger rig in early August, 1983. Permanent monitoring well details are shown in figure 8.

Well No.	Dimension (ft)		Elevation of MP (ft MSL)	Elevation of land surface (ft MSL)
	A	B		
N1-60	59.3	62	753.17	750.44
N1-70	69.2	72	753.34	750.52
N1-80	79.0	82	753.16	750.12
N2-50	49.2	52	752.56	749.77
N2-60	59.3	62	752.55	749.84
N3-40	38.9	42	751.84	748.77
N3-55	54.1	57	751.68	748.75
N4-50	49.5	52	750.88	748.36
N4-60	59.3	62	750.91	748.21

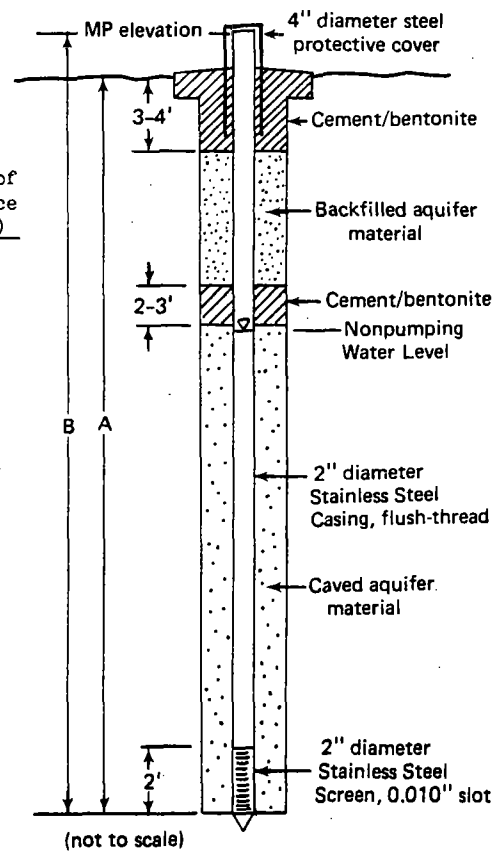


Figure 8. ISWS/IEPA monitoring well construction details.

Due to problems associated with organic compounds leaching from and adsorbing to polyvinyl chloride (PVC) casing and screen,^{17,18} flush-threaded stainless steel casing and screen, 2-inches in diameter, were used for all wells. The screens were two feet long with 0.01-inch wire-wound slot openings. All materials associated with the monitoring well construction, including the drill rig, were steam cleaned prior to the commencement of drilling to avoid organic contamination from cutting oils and grease. Prior to use, the casing and screen materials were kept off-site in a protected area.

To insure that the sandy materials would not collapse the hole after drilling, casing lengths and the screen were screwed together above ground and placed down the inside of the augers before the auger flights were pulled out of the hole. Sand below the water table collapsed around the screen and casing as the augers were removed. To help prevent vertical movement of water down along the casing, a wet bentonite/cement mixture was placed in the annulus just above the water table to a thickness of two to three feet. Cuttings (principally clean, medium to fine sand) were backfilled above the bentonite/cement seal to within four feet of land surface. Another bentonite/cement mixture was placed to form a surface seal, preventing drainage of surface water down along the well casing. A four-inch diameter steel protective cover with locking cap was placed around the protruding casing and into the surface seal to protect against vandalism.

The nine wells were drilled at four locations with paired wells at three sites and a nest of three wells at one site (figure 9). The locations were based on the analytical results of the samples taken from the temporary wells and basic knowledge of the groundwater flow direction. Locations were numbered as Nests 1 through 4 (N1 - N4) in order of their construction.

Nest 1, located immediately north of Hononegah Country Estates along Hononegah Road (and approximately 1000 feet west of Illinois Route 251), consists of three wells drilled to 60, 70, and 80 feet. Nest 2, located approximately 2100 feet south of McCurry Road along the west side of Route 251, consists of two wells 50 and 60 feet deep. Nest 3 is 800 feet south of Nest 2 along Route 251 and consists of two wells constructed to 40 and 55 feet. Nest 4 is located on the east side of Route 251 between Nests 2 and 3 (approximately 275 feet south of Nest 2) and also consists of two wells 50 and 60 feet deep.

Groundwater Flow Pattern and Rate of Movement

Mapping the groundwater elevation is vitally important to any groundwater quality investigation. Only with this information can groundwater flow direction be determined and potential source locations be identified.

Precise water level measurements (depth to water below ground surface) were taken in the nine monitoring wells constructed during the course of the investigation. A topographic level circuit determined the measuring point elevations (the top of the well casing), in feet above mean sea level, at each well. Groundwater elevation maps were produced by subtracting depth-to-water measurements from ground elevations. Groundwater level measurements were taken on a monthly basis during well sampling periods.

Similarly, the rate of groundwater movement is important in groundwater investigations. Knowing the rate of movement and length of time a particular well has been contaminated, the probable distance to potential sources can be estimated. Conversely, knowing a contaminant source and the rate of groundwater movement, estimates can be made for how long it might take for a

contaminant to reach a particular area. For this investigation, contaminant movement with the groundwater formed a basis for determining the period of exposure to which residents within the affected area had been subjected.

A form of Darcy's Law is the basic equation used to describe the rate (velocity) of groundwater movement:¹⁹

$$v = \frac{KI}{7.48}$$

where,

v = rate of groundwater movement, ft/day

K = hydraulic conductivity or permeability, gal/day/ft²

I = hydraulic gradient or slope of water table, ft/ft

7.48 = gallons per cubic foot

This mathematical expression assumes that flow occurs through the entire cross section of geologic materials without regard to solids and pores.

Actually, flow is limited to the pore spaces available to transmit water.

The actual flow velocity is:

$$v_a = \frac{v}{n} = \frac{KI}{7.48n}$$

where,

v_a = advective or interstitial pore velocity, ft/day

n = effective porosity, the percent of the material consisting of interconnected pore space, unitless

To solve this equation, three quantities must be known or determined,

1) the hydraulic gradient, 2) the hydraulic conductivity of the material through which the water is moving, and 3) the effective porosity of the material. The hydraulic gradient can be determined from groundwater contour maps by determining the change in elevation and the distance over which that

change takes place. The effective porosity is very difficult to measure in the field or the laboratory. For permeable aquifers such as the sand and gravel present within the study area, the effective porosity will be very close to the total porosity. It can also be estimated as the specific yield, or the percent of a given volume of saturated material that drains by gravity. Because of the lack of actual effective porosity data, estimates usually are made from tabulated values of total porosity which have been compiled for similar geologic materials.

The remaining parameter needed to calculate the groundwater flow rate is the hydraulic conductivity. Hydraulic conductivities can be determined by a variety of methods. The usual approach is by conducting a production test: pumping a well at a constant rate and measuring the aquifer response to pumpage in terms of the drop in water levels in the pumped well and surrounding observation wells.^{20,21,22}

However, a relatively new technique for performing the hydraulic testing was conducted on the nine monitoring wells following a procedure outlined by Prosser.²³ The method proved to be very useful on the highly permeable and rapidly responding geologic materials in the study area.

The testing procedure is based on the slug-test method presented by Hvorslev.²⁴ As originally presented, an instantaneous change in head is produced in a well either by removing or introducing a known volume of water to the well. The water level response to this change in head is related to the hydraulic conductivity of the materials in which the well is completed.

Hvorslev's slug-test method is very useful when materials of low conductivity are being tested as it does not require removing more water from a formation than it is capable of yielding. Recent use of small diameter wells for water quality monitoring which are similarly incapable of producing

large volumes of water, even in highly conductive conditions, also have made the slug-test method attractive. However, the rapid response to the induced head difference in highly conductive conditions, sometimes only a matter of seconds, is difficult to measure with physical techniques (i.e., with chalked steel tape or electric dropline).

The technique developed by Prosser²³ circumvents this problem by placing an electronic pressure transducer beneath the water surface in the well to be tested. The transducer can quickly relay water level data to a recorder at ground level. To induce a head difference, water is displaced by applying air pressure to the well casing. Once equilibration to the desired water displacement is achieved, sudden release of the air pressure produces an instantaneous head difference. The water level response measured by the transducer can be recorded on magnetic tape or drawn on a strip-chart recorder. This method was used successfully on each of the nine monitoring wells constructed for the investigation.

An Enviro-Labs submersible pressure transducer was coupled with a Cole-Parmer dual channel strip-chart recorder to give a "hard" copy of the aquifer water level response. To achieve a desired 0.01 foot resolution on water level measurements, a 0 to 5 PSIG transducer was selected (instrument precision was limited to 0.1 percent of its range). This limited the maximum amount of water which could be displaced to 11.5 feet (2.3 feet/psi). About 8 feet of water was displaced during the testing procedure. An extremely rapid response in water levels made the strip-chart recorder very useful; once pressure was released original static water levels usually were achieved within one minute. A chart speed of 30 cm/min produced an easily readable copy of the water level response. An example of the output produced by the transducer/strip-chart recorder appears in figure 10.

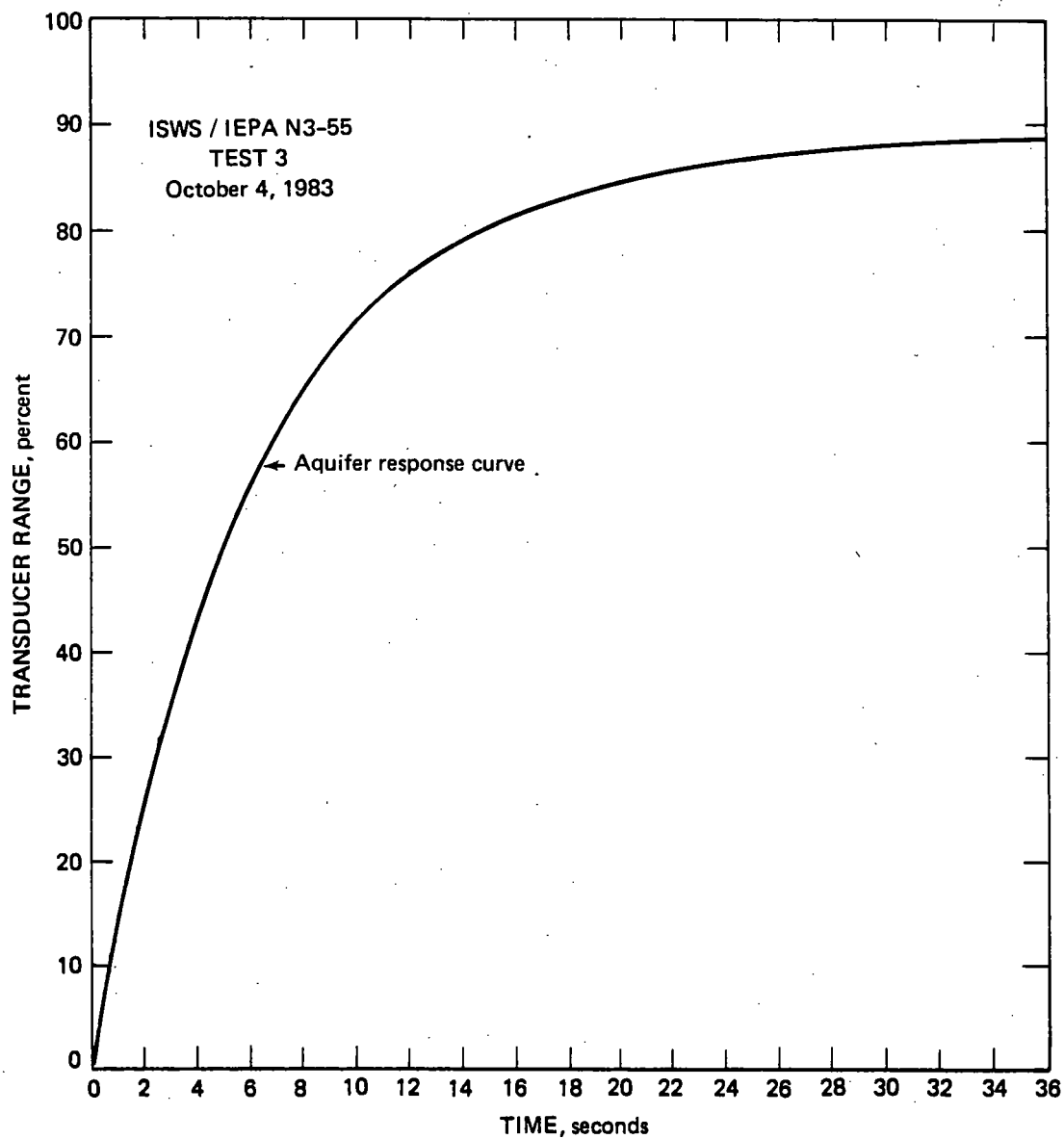


Figure 10. Output produced on strip-chart recorder during pressure test on ISWS/IEPA monitoring well N3-55.

A graphical analysis of the water level data involves a plot of the ratio of unrecovered head to total change in head vs. the logarithm of time since depressurization occurred. The method is explained in detail by Hvorslev²⁴ and Freeze and Cherry.²⁵ The equation used to solve for hydraulic conductivity is:

$$K = \frac{r^2 \ln (L/R)}{2L T_0}$$

where,

K = hydraulic conductivity, cm/sec

r = radius of well, cm

R = effective radius or radius of intake, cm

L = length of well screen, cm

T₀ = basic time lag, defined as where a straight line
projection of the unrecovered head ratio passes 37
percent, sec

Figure 11 is a representation of the variables considered in this equation and an analytical plot of the data produced from the strip-chart shown in figure 10.

Groundwater Sample Collection and Analysis

Groundwater samples were collected from three types of wells at various times during the study. Sampling procedures varied depending on the type of well and the intent of the sampling. The types of wells encountered and a description of their use as sampling points can be summarized as follows:

- 1) Private domestic, industrial, and commercial wells. These wells were in existence prior to the start of the investigation and serve as water sources to the owners. These wells account for the largest

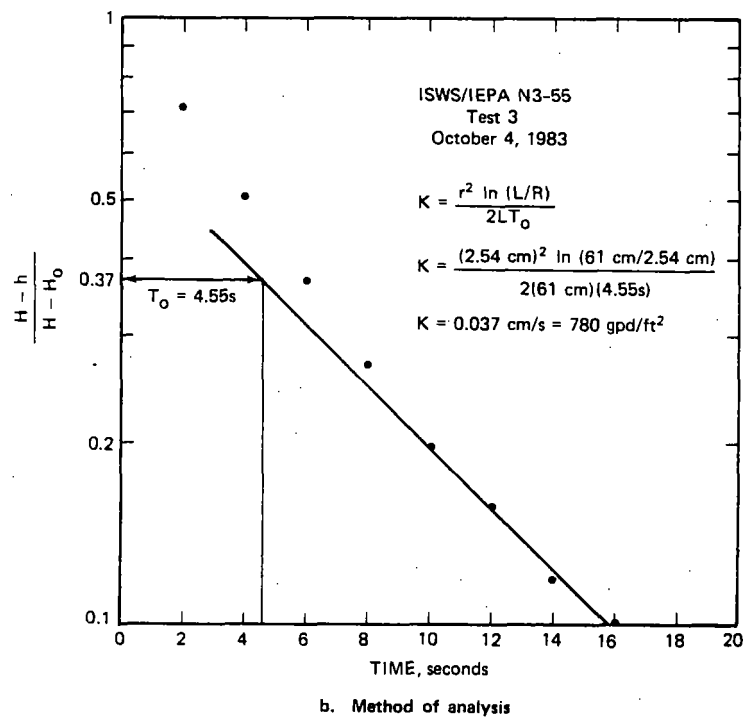
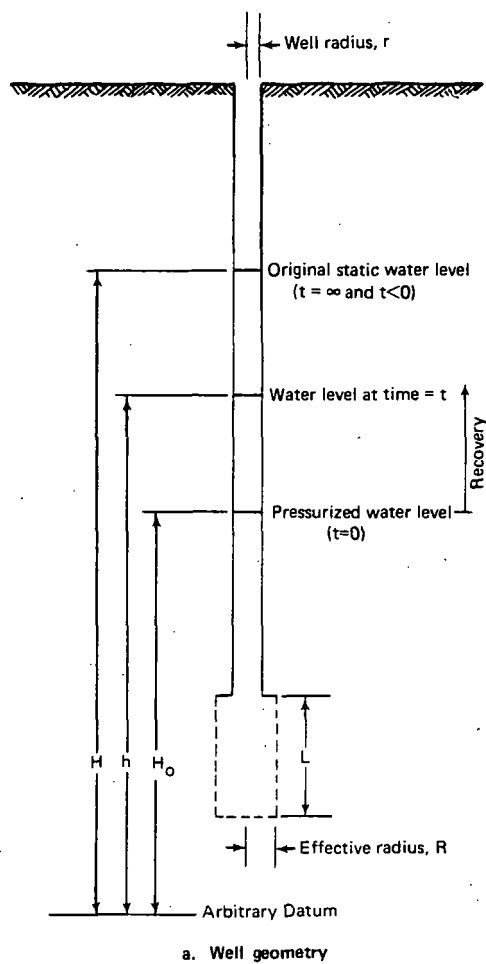


Figure 11. Hvorslev slug-test a) well geometry and b) method of data analysis.

number of the wells sampled during the investigation. Most of the domestic wells in the area are 4 inches in diameter, have been drilled to depths from approximately 65 to 75 feet deep, and are equipped with screens 2 to 5 feet long. As will be discussed, the wells within Hononegah Country Estates and Moore Haven Subdivisions provided much of the data for description of the VOC plume.

- 2) Temporary monitoring wells. These five wells were called "temporary" because after sampling, the casing and screen were removed and the hole filled and sealed. Sampling of these wells was an initial attempt to confirm the presence of VOCs upgradient from the affected subdivisions and to aid in the location of permanent monitoring well installations.
- 3) Permanent monitoring wells. These nine wells were constructed after the sampling results of the five temporary wells were known. The wells were constructed and subsequently sampled using techniques suitable for detecting trace levels of volatile organics.

Where available, outside faucets were used as sampling points for the private wells. This eliminated unnecessary entry of homes and bypassed most domestic water treatment units. This became increasingly important when many people began installing granular activated carbon filters to reduce VOC concentrations in their drinking water. Faucets were run approximately 5 minutes to allow the water line to flush with fresh water prior to sampling. Temperature readings were used to indicate when fresh water was reaching the tap but often, water pressure changes and audible sounds gave indication that the well pump had turned on and fresh water was being supplied to the system.

Samples were collected in standard 40 ml glass VOC vials with teflon septums. Duplicate samples were collected at each well in case of breakage during transport and to provide additional water for reanalysis. The vials were rinsed with the sampled water prior to sealing. Care was taken to seal the bottles such that no air bubbles were present in the vial. The sample was identified and placed in an insulated container for transport to the laboratory.

Over 130 samples were collected in this manner between January and December 1983. Initial samples gathered by the County Health Department in January and February were analyzed by the Sanitary District of Rockford and the University of Illinois' College of Medicine at Rockford. Analytical results of duplicate samples by the Rockford School of Medicine, Illinois Environmental Protection Agency, and Illinois Department of Public Health were found to vary considerably (sometimes by as much as a factor of three). It was not specifically determined why the discrepancies occurred; even though the samples were collected under identical conditions (pumping mechanisms, sampling personnel, sample bottle, etc.), the storage and handling of the sample once it left the well site, the length of the storage period prior to analysis, and the comparability of analytical methods combine to introduce bias to the analytical results. While quantitative differences between lab results were noted, the results were comparable in a qualitative sense. Therefore, the most contaminated sample was consistently the same from lab to lab and similarly all other samples could be ranked from highest to lowest. To maintain consistency of handling and analysis, it was imperative that one laboratory be responsible for all analyses. By mid-March, all samples were being sent to the Division of Laboratories, State Department of Public Health in Chicago.

Samples from wells within Hononegah Country Estates and Moore Haven Subdivisions were collected on at least a monthly basis between March and October 1983 and for the period between May 10 and July 5, on a weekly basis. It was during this intensified sampling effort that an attempt was made to sample every household within the affected area. This was as much a response to public concern over personal drinking water quality as it was an effort to establish the concentrations of contaminants within the VOC plume. Letters were sent by the County Health Department to well owners detailing the results of their well sample analyses and four newsletters were distributed (bimonthly) within the affected subdivisions to help keep the residents informed of project developments.

A final "mass" sampling of 49 domestic wells was conducted in mid-October to assess the quality of water in wells associated with individuals and families who had volunteered to participate in the epidemiological study being conducted by the County and State Health Departments and the Rockford School of Medicine.

Concurrent with sample collection in the subdivisions, wells upgradient of the subdivisions were sampled to establish the presence of VOCs outside the subdivisions. In July, groundwater samples were collected from the temporary wells. Samples were taken at 40 and 50 feet from each of five holes as the respective depths were reached during drilling. Sampling was conducted with a stainless steel bailer lowered to the bottom of the well screen as soon as the drill stem was removed from the well. The bailer and retrieval chain were steam-cleaned before each sample was collected. Samples

from the temporary wells were also kept in standard 40 ml VOC vials previously rinsed with sample water. Again, care was taken to seal the sample bottles so they contained no air bubbles. A sample of distilled water was kept with the groundwater samples to serve as a field blank.

To meet time constraints for sending samples back to the laboratory in Chicago, a polyphosphate drilling additive was used to aid the drilling of TW5 (see figure 8). TW5 was the only hole drilled using this additive. To determine potential interferences from this additive, a sample of the drilling fluid used at TW5 was taken.

It must be emphasized that samples collected from the five temporary wells were solely to establish the presence of VOCs upgradient of the affected subdivisions and to aid in the location of permanent monitoring well sites. Sampling procedures for these wells were not as rigorous as normally should be exercised when sampling for volatile organics in the 100 µg/L concentration range.

By the end of August, the results of the temporary well samples had been evaluated and the permanent ISWS/IEPA stainless steel monitoring wells had been constructed. Sampling of these wells was conducted using more sophisticated techniques. Prior to sample collection at each well, a static water level measurement was made and the amount of water standing in the well column was calculated (one well "volume"). Recent work has shown that water quality can be changed due to exposure to the air and well casing while standing in the well column.^{17,26} Due to the high yield capabilities of this aquifer, removal of one well volume of water was considered appropriate for providing a "representative" sample of formation water.

Initial samples (August 30-31, 1983) from the ISWS/IEPA wells had to be bailed due to the failure of a submersible diaphragm pump. After one well volume of water was withdrawn with a stainless steel bailer, an all-teflon bailer was used to collect the water sample. The teflon bailer utilized a double check valve arrangement to assure sampling from a specific depth. The bailer also contained a bottom-release spout which reduces the effects of volatilization which might occur by mixing with air during pouring from normal bailers. Both bailers were thoroughly rinsed with distilled water between wells to reduce the potential for cross-contamination between wells. A sample of distilled water passed through the teflon bailer after rinsing was collected during the sampling effort to determine the magnitude of a potential cross-contamination problem.

Subsequent sampling (on October 5-6 and November 30, 1983) of the ISWS/IEPA monitoring wells was conducted with a submersible diaphragm pump designed at the State Water Survey specifically for groundwater quality monitoring. The pump is operated with compressed gas (air or nitrogen is commonly used); no contact between gas and water sample is made. All pump parts are stainless steel or teflon. All discharge and gas pressure tubing was teflon. The pump and all tubing were thoroughly rinsed with distilled water before moving to each well and the same sampling procedures were followed as when bailing, i.e. removal of one well volume of water before sample collection.

All VOC analyses were performed by the Illinois Department of Public Health, Division of Laboratories for this investigation. Analyses were conducted by purge and trap gas chromatographic method.²⁷ Volatile hydrocarbons are extracted by bubbling an inert gas (i.e., nitrogen) through the water sample, then trapped on a Tenax (2,6-diphenylene oxide polymer) column.

After thermal desorption, the compounds are flushed onto an analytical column (8 feet x 0.1 inch I.D. stainless steel packed with Carbopack B 60/80 mesh coated with 1 percent SP-1000). A gas chromatograph separates the halocarbons which are then detected with either a Hall-type electrolytic conductivity detector or an electron capture detector. A detection response forms a peak on a strip chart recorder which is compared to peaks generated by appropriate standards. The system is capable of measuring a minimum concentration of 0.5 µg/L.

Modeling

The primary focus of this project was to provide information to local health officials (principally investigators at the University of Illinois' College of Medicine in Rockford, the Environmental Health Division of the Winnebago County Department of Public Health, and the Illinois Department of Public Health) describing the volatile organic doses local residents have ingested through their drinking water. This would include the length of time and concentration of volatile organics that may have been in their water at their residence within the affected subdivision.

A random-walk solute transport code, developed at the Illinois State Water Survey,²⁸ was used to simulate the transport of the organic contaminants through the aquifer. The code simulated two-dimensional steady flow on a 15 by 41 regularly spaced finite difference grid (see figure 12). The head calculation subroutine (HSOLV) was not called; rather, a uniform flow field with a prescribed velocity was used and the contaminant was introduced into the model flow field at suspected source points.

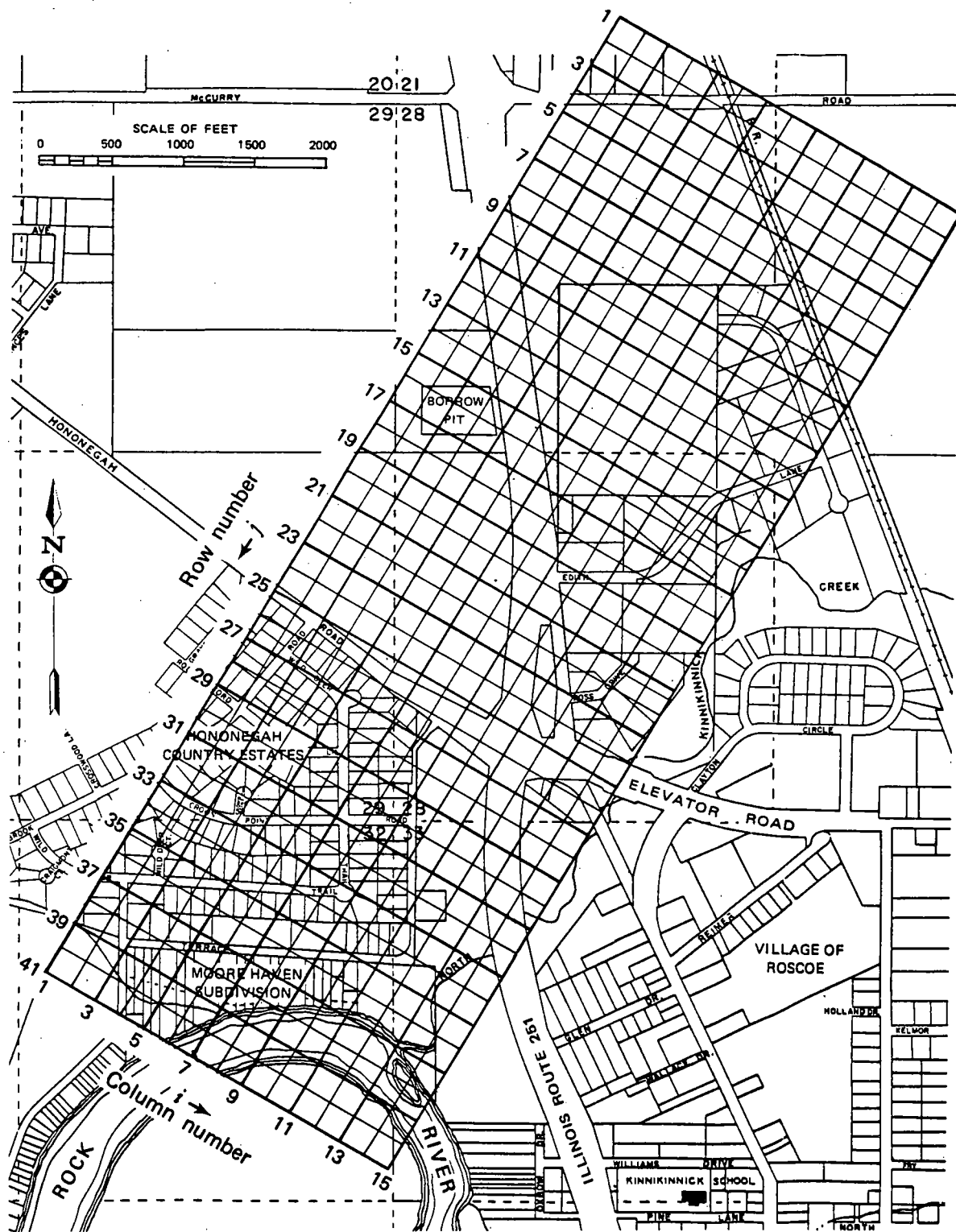


Figure 12. Computer model finite difference grid.

Several computer runs were necessary to properly calibrate the simulated flow field and contaminant path to the observed field conditions. Several additional runs were necessary to match the contaminant plume strength (concentration) with the dispersivity (spread). Due to the nature of the plume, with the leading edge already having reached the Rock River, more confidence was placed on estimating the transverse dispersivity than longitudinal dispersivity.

Once the contaminant plume geometry was reasonably simulated, nodal data were used to generate graphs of concentration versus time for nodes of interest. Nodes of interest correspond approximately to residential well locations within Hononegah Country Estates and Moore Haven Subdivisions. The area under the curves of concentration versus time for a particular location were multiplied by an estimate of the amount of water ingested by an individual during the given time period to provide an approximation of an individual's dose (exposure) from organic constituents in the drinking water.

FIELD RESULTS

Groundwater Elevations and Direction of Movement

Groundwater elevations or "water table" maps were prepared from water level data observed during the three sampling periods in August, October, and November, at the permanent ISWS/IEPA monitoring well installations. Table 4 presents the groundwater elevation data used to construct the maps in figures 13, 14, and 15. The groundwater contours constructed from the 1983 data compare closely with those constructed in the fall of 1982 as part of the previous nitrate study.¹ The Fall 1982 contour map is shown as figure 16.

While a continuous hydrograph of groundwater levels was not recorded during this investigation, the data collected during the nitrate study (March-December, 1982) showed groundwater elevations varied approximately three feet during the year in response to recharge. A comparison of the 1982 contour maps and the hydrograph showed that these seasonal changes in groundwater elevation did not change the pattern of the groundwater contours. Groundwater pumpage from the numerous domestic wells within the subdivisions situated along the Rock River do not appear to alter the groundwater contours.

Groundwater moves perpendicularly to water surface contours. From the contoured data it can be seen that groundwater is moving from the surrounding uplands and terraces to the Rock River. Within the affected area movement is generally from north-northeast to south-southwest with a slight bend as the Rock River is approached. Movement is essentially north to south beneath the Hononegah Country Estates and Moore Haven Subdivisions.

Table 4. Groundwater Elevations at ISWS/IEPA Wells

Well number	Measuring point elevation (top of casing, ft MSL)	Groundwater Elevation (ft MSL)		
		August 30, 83*	October 4, 83*	November 30, 83
N1-60	753.17	717.40	717.12	717.35
N1-70	753.34	717.42	717.13	717.37
N1-80	753.16	717.34	717.04	717.23
N2-50	752.56	722.07	721.65	721.54
N2-60	752.55	722.08	721.65	721.55
N3-40	751.84	720.87	720.48	720.60
N3-55	751.68	720.88	720.50	720.62
N4-50	750.88	721.91	721.49	721.42
N4-60	750.91	721.89	721.45	721.37

*Elevations at wells upgradient of ISWS/IEPA wells also were available for construction of figures 15 and 16.



Figure 13. Shallow groundwater elevations, August 30-31, 1983.

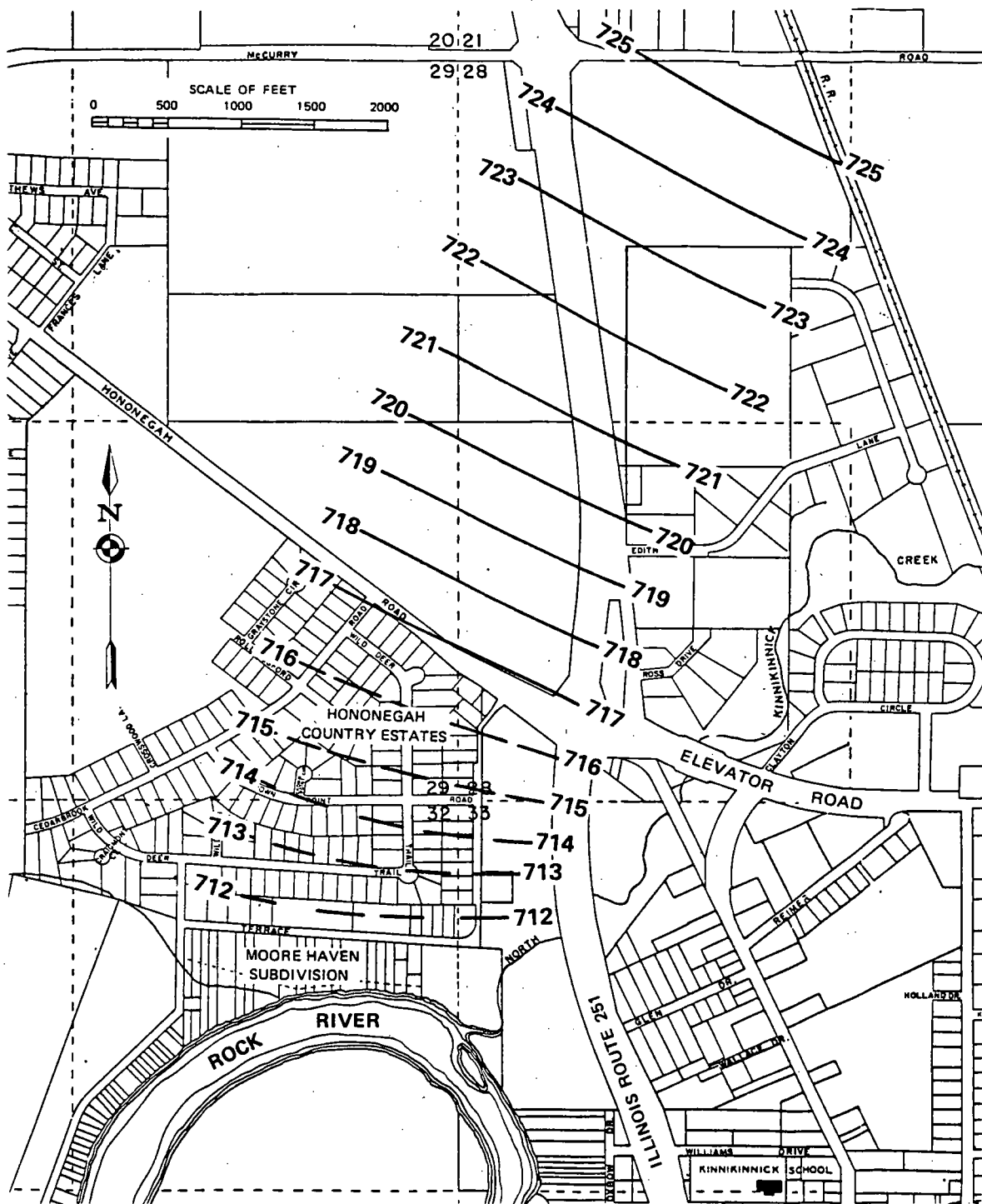


Figure 14. Shallow groundwater elevations, October 5-6, 1983.

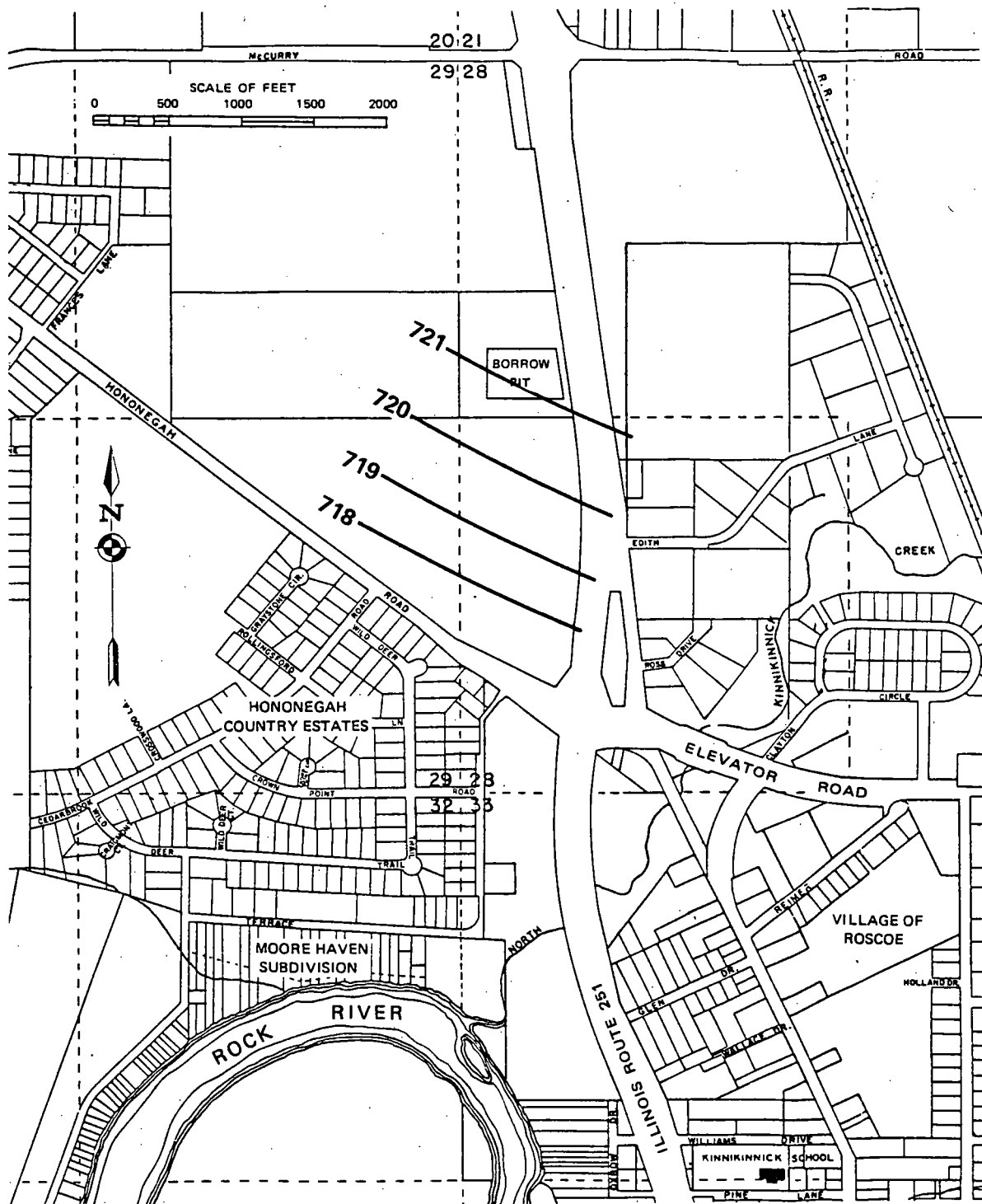


Figure 15. Shallow groundwater elevations, November 30, 1983.

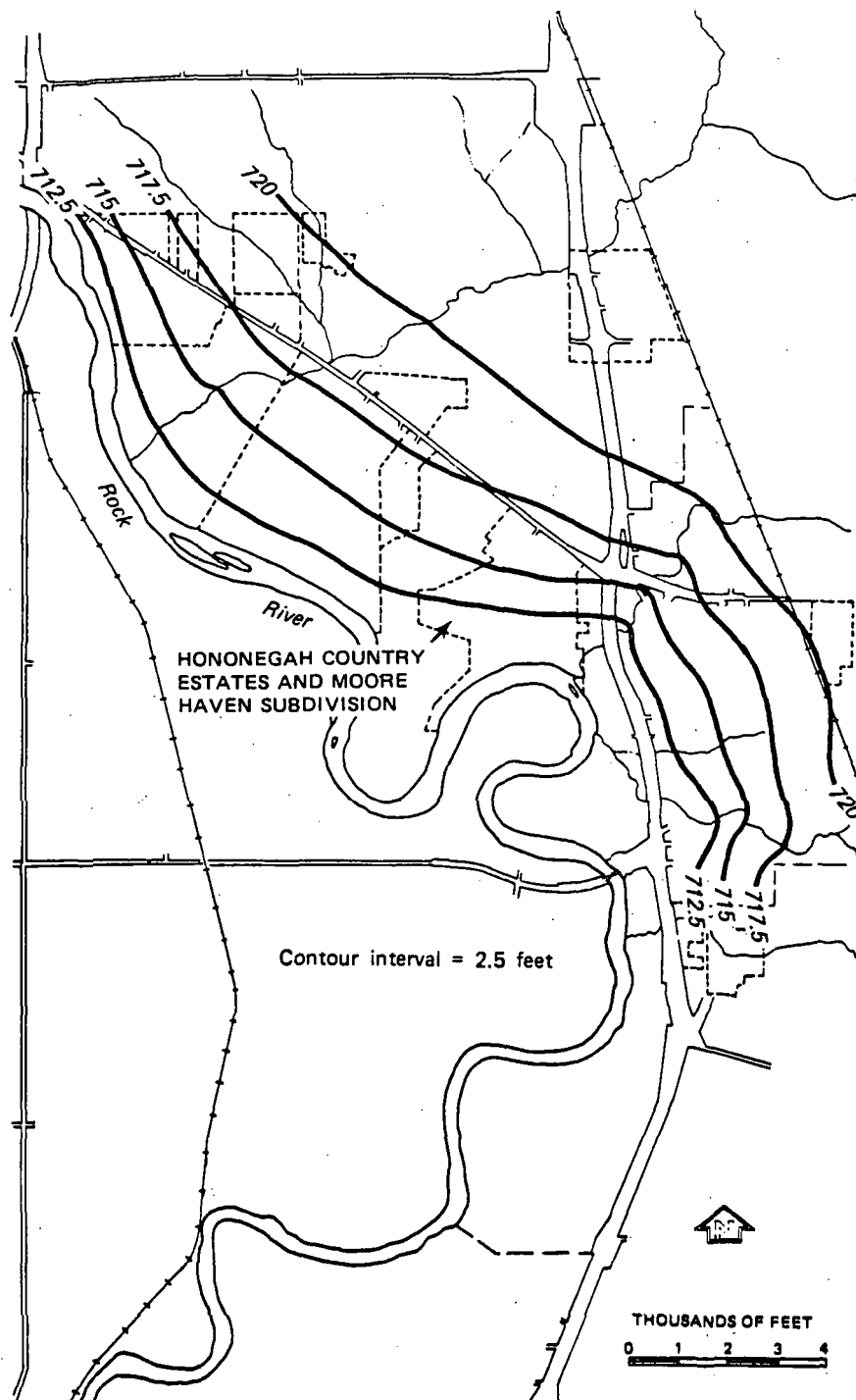


Figure 16. Shallow groundwater elevations, Fall 1982 (from Wehrmann, 1983).

The water table slope beneath the study area was essentially the same throughout the period of investigation, approximately 0.0022 ft/ft. The data indicate that the slope of the water table was slightly less, 0.0019 to 0.0020 ft/ft, in the upgradient portions of the study area, and somewhat greater, 0.0025 to 0.0027 ft/ft, as the Rock River was approached.

Hydraulic Conductivity and Rate of Groundwater Movement

Hydraulic conductivity "pressure" tests were conducted on each of the nine ISWS/IEPA monitoring wells. Three tests were conducted at each well; a value representative of the hydraulic conductivities calculated at each well appears in Table 5. Conductivities ranged from a low of 650 gpd/ft² (3.1×10^{-2} cm/s) at Well N1-70 to a high of 2200 gpd/ft² (1.0×10^{-1} cm/s) at Well N4-60. The conductivity at N4-60 is two to three times larger than the conductivities calculated for any of the other wells. This value may be real (an anomaly in the aquifer) but is more likely the result of a discrepancy in the testing procedure. The consistency of the geologic materials found in all the monitoring wells would indicate that the calculated conductivity at Well N4-60 may be in error. Excluding Well N4-60, the highest conductivity is 1000 gpd/ft² (4.7×10^{-2} cm/s) at Well N2-60. Similarly excluding Well N4-60, the average hydraulic conductivity for the wells tested is 800 gpd/ft² (3.8×10^{-2} cm/s).

Table 5. Hydraulic Conductivities at ISWS/IEPA Monitoring Wells

Depth of well tested (feet)	Hydraulic Conductivity, gpd/ft ² (cm/s)			
	<u>Nest 1</u>	<u>Nest 2</u>	<u>Nest 3</u>	<u>Nest 4</u>
40			870(4.1x10 ⁻²)	
50		830(3.9x10 ⁻²)		910(4.3x10 ⁻²)
55			770(3.6x10 ⁻²)	
60	700(3.3x10 ⁻²)	1000(4.7x10 ⁻²)		2200(1.04x10 ⁻²)
70	650(3.1x10 ⁻²)			
80	720(3.4x10 ⁻²)			

As discussed earlier, Darcy's Law is used to calculate rates of groundwater movement. Using a hydraulic gradient of 0.0022 ft/ft, a hydraulic conductivity of 800 gpd/ft² (3.8 x 10⁻² cm/s), and assuming an effective porosity of 0.25 (a lower bound for porosities listed by Freeze and Cherry, 1979), the interstitial velocity of the groundwater beneath the study area is:

$$v_a = \frac{KI}{7.48n}$$

$$v_a = \frac{(800 \text{ gpd/ft}^2) (0.0022 \text{ ft/ft})}{(0.25)(7.48 \text{ g/ft}^3)} = 0.94 \text{ ft/day}$$

For the purposes of this study, the rate of groundwater movement was estimated to be approximately 1 ft/day.

Groundwater Quality

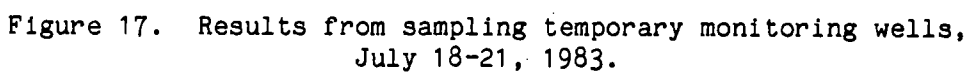
Due to the construction and sampling methods employed for the temporary wells, the quantitative aspects of the sampling results should not be over-emphasized. However, important conclusions can be made in a qualitative

sense. These wells achieved their intended purpose by confirming the presence of VOCs directly upgradient of the subdivisions and providing information for the location and depth of the permanent monitoring wells.

The concentrations of TCE detected in the temporary monitoring wells are shown in figure 17. Of particular interest are the relatively low TCE concentrations found in TW1. Concentrations were 18 and 84 $\mu\text{g/L}$ at 40 and 50 feet, respectively. These concentrations are much less than the TCE concentrations found in the other temporary wells at the same depths and quite different from the 2178 $\mu\text{g/L}$ TCE found in a nearby residential well sampled the same week. The residential well is approximately 65 feet deep, 15-25 feet deeper than the samples collected at TW1.

Judging by the greater concentrations at shallower depth at locations upgradient from TW1 and at greater depth just downgradient from TW1 it appears that vertical migration of contaminant has occurred. TCE is known to be approximately 1.5 times denser than water. The downward migration of the TCE might also be in response to recharge of fresh water which occurs from the land surface as the groundwater moves horizontally beneath it. Whatever the reason, this information indicated that monitoring wells should be completed at depths greater than 50 feet near the subdivision.

Wells TW4 and TW5 were placed along the southern boundary of a depression covering approximately 2 acres that appears to have been a borrow pit used for the construction of Route 251. An old airplane runway, noted on old topographic maps, ran east to west along the southern edge of this depression. The presence of debris and the possibility that this depression had been used to dispose of aviation-related materials (oil, etc.), suggested that it may be a VOC contaminant source. The presence of greater concentrations of TCE at TW4 and TW5 supports this theory, however, TCE concentrations



in TW2 and the commercial wells along the east side of Route 251, not directly downgradient of the depression, indicated that this area could not be the only source, if a source at all. In addition, the polyphosphate additive used during drilling at TW5, a sample of which was analyzed just prior to the TW5 sample, created acute problems with the laboratory equipment. Organic concentrations from this sample were not determined; the equipment had to be shut down and completely cleaned before further samples could be analyzed. This may have further influenced the quantitative aspects of the results at TW5.

As will be described in the next sections, the positions of TW4 and TW5 place them on the same flow path as the main VOC contaminant path through Hononegah Country Estates and Moore Haven Subdivisions. Permanent monitoring well locations were chosen upgradient of the depression to determine if a source further upgradient was likely. While positions of the permanent monitoring sites do not necessarily eliminate the depression from consideration as a potential source, data from the permanent wells indicate that another source is involved. Also, the "fingerprint" of the samples collected at TW4 and TW5, or the percentage of specific chemicals which comprise the VOC total (i.e., TCE, trans 1,2-dichloroethylene, 1,1,1-trichloroethane, etc.), was the same as that found in all the other wells sampled, indicating the source for all wells is likely the same.

The results of VOC analyses as reported by the Illinois Department of Public Health for samples collected from the ISWS/IEPA monitoring wells are reported in Table 6. TCE was the major component of the total VOC concentrations accounting for over 95 percent of the total VOCs detected. TCE concentrations ranged from 43 to 1112 $\mu\text{g/L}$, 41 to 1358 $\mu\text{g/L}$, and 40 to 1185

µg/L in August, October, and November, respectively. These variations reflect the differences in location and depth at which the samples were collected (see figure 9 for monitoring well locations).

Depending on the date of sampling, the 60 or 70 foot wells at Nest 1 (N1-60 and N1-70) generally showed the greatest contamination of any of the permanent monitoring wells. Below 70 feet, TCE concentrations decreased; Well N1-80 had TCE concentrations 40 to 60 percent lower than those found in N1-70. Monitoring well N4-50 had TCE concentrations similar to those found in Wells N1-60 and N1-70. This data supports the temporary well findings; the contaminant plume has vertically stratified within the aquifer and is descending as it approaches the Rock River.

The shallow well at Nest 2 (N2-50) and the deep well at Nest 3 (N3-55) yielded the lowest TCE concentrations of any of the ISWS/IEPA monitoring wells throughout the sampling period. The shallow wells at Nests 3 and 4, N3-40 and N4-50, and the deep well at Nest 2, N2-60, yielded TCE concentrations in roughly the same amounts.

Figure 18 conceptually illustrates a cross section of the TCE plume looking in the general direction of groundwater flow in the vicinity of ISWS/IEPA monitoring well nests 2, 3, and 4 (see figure 9 for the cross section location). The plume appears as a series of concentric rings with greater concentrations toward the center of the plume. Adequate data does not exist to show the exact configuration of the TCE contours. Wells N2-50 and N3-55 penetrate the same general zone of contamination (less than 100 µg/L TCE). Wells N2-60, N3-40, and N4-60 are within a zone containing from 250 - 500 µg/L TCE. Well N4-50 contains the greatest amount of TCE observed at these three monitoring well nests, between 700 and 900 µg/L.

Table 6. TCE and Total VOC Concentrations at ISWS/IEPA Monitoring Wells
(As reported by IDPH)

Well No.	August	30-31, '83	October	5-6, '83	November	30, '83	March	13, '84
	TCE	Total VOC	TCE	Total VOC	TCE	Total VOC	TCE	Total VOC
N1-60	1112	1137	660	676	1185	1217	775	803
N1-70	460	476	1358	1382	Broken in Transit		718	736
N1-80	281	293	544	553	409	422	452	462
N1-100*	-	-	-	-	-	-	61	62
N2-50	43	45	59	61	40	42	-	-
N2-60	293	299	403	410	356	368	-	-
N3-40	267	274	333	341	213	229	-	-
N3-55	59	63	41	44	Not available		-	-
N4-50	829	850	749	766	959	982	-	-
N4-60	402	422	254	273	143	165	-	-
Bailer Sample A	1	5						
Bailer Sample B	0	2						
Field Blank			0	Tr			0	13**
Trip Blank							1	21**

*Well built on March 6, 1984 as prerequisite to central well supply system construction for subdivisions

**Field and trip blanks from CBC/Aquasearch personnel during sampling being observed by IEPA as prerequisite to central well supply

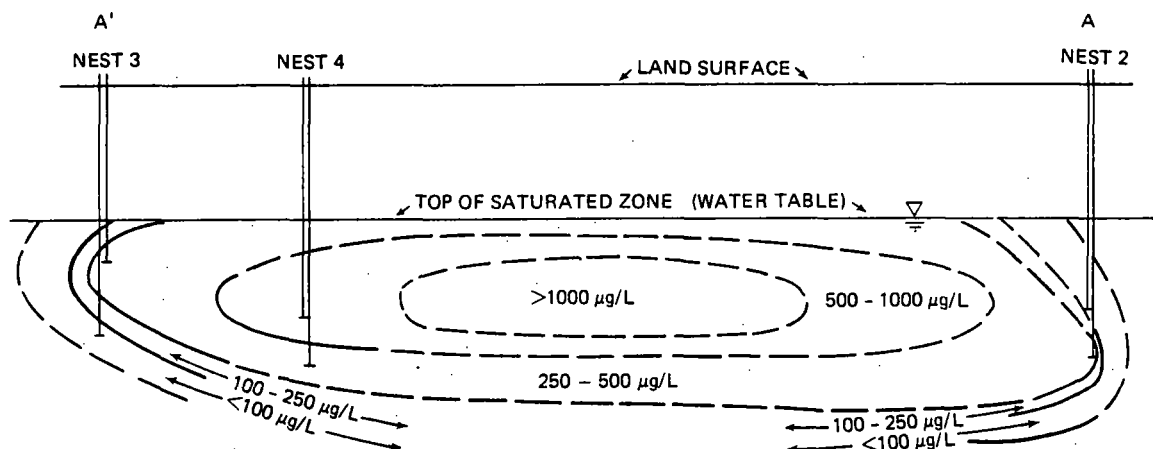


Figure 18. Cross section through ISWS/IEPA monitoring nests 2, 3, and 4, looking in the direction of groundwater flow.

A plume of this configuration explains why the shallower wells at Nests 3 and 4 contain greater TCE concentrations than their deeper counterparts and why the converse is true at Nest 2. The zone of greatest TCE concentration probably has not been penetrated by the monitoring wells along Route 251. Based on the groundwater flow direction and the plume configuration as it passes beneath Hononegah Country Estates and Moore Haven Subdivisions, the location of a zone containing TCE concentrations greater than 1000 $\mu\text{g/L}$ should be situated between Nests 2 and 4. This concept may also explain why greater TCE concentrations were found at TW4 and TW5.

A contour map of the TCE concentrations in domestic wells located within Hononegah Country Estates and Moore Haven Subdivisions shows the organic contaminant plume has migrated in a very distinct path to the Rock River (figure 19). The map was prepared from approximately 100 samples collected between January and August 1983.

The plume closely follows the groundwater flow path indicated from the groundwater contour maps. The greatest concentrations, from 1000 to 2000 $\mu\text{g/L}$ TCE, appear in a band approximately 200 feet wide through the center of the plume. TCE concentrations decrease rapidly to 50 $\mu\text{g/L}$ or less to the east and west. The western edge of the plume appears much more distinctly than the eastern edge. To the west, TCE concentrations clearly drop to trace levels within 400 to 800 feet of the central axis of the plume. To the east, however, 50 $\mu\text{g/L}$ TCE is still evident 800 feet from the plume's central axis.

The apparent "smearing" of the plume along its eastern boundary may be due to the lack of sampling points (wells) located along the eastern side of the TCE plume. Between Edgemere Terrace and Route 251 there is undeveloped farmland with no wells. It is quite possible the plume forms a distinct boundary within this area but sampling points are not available for such a

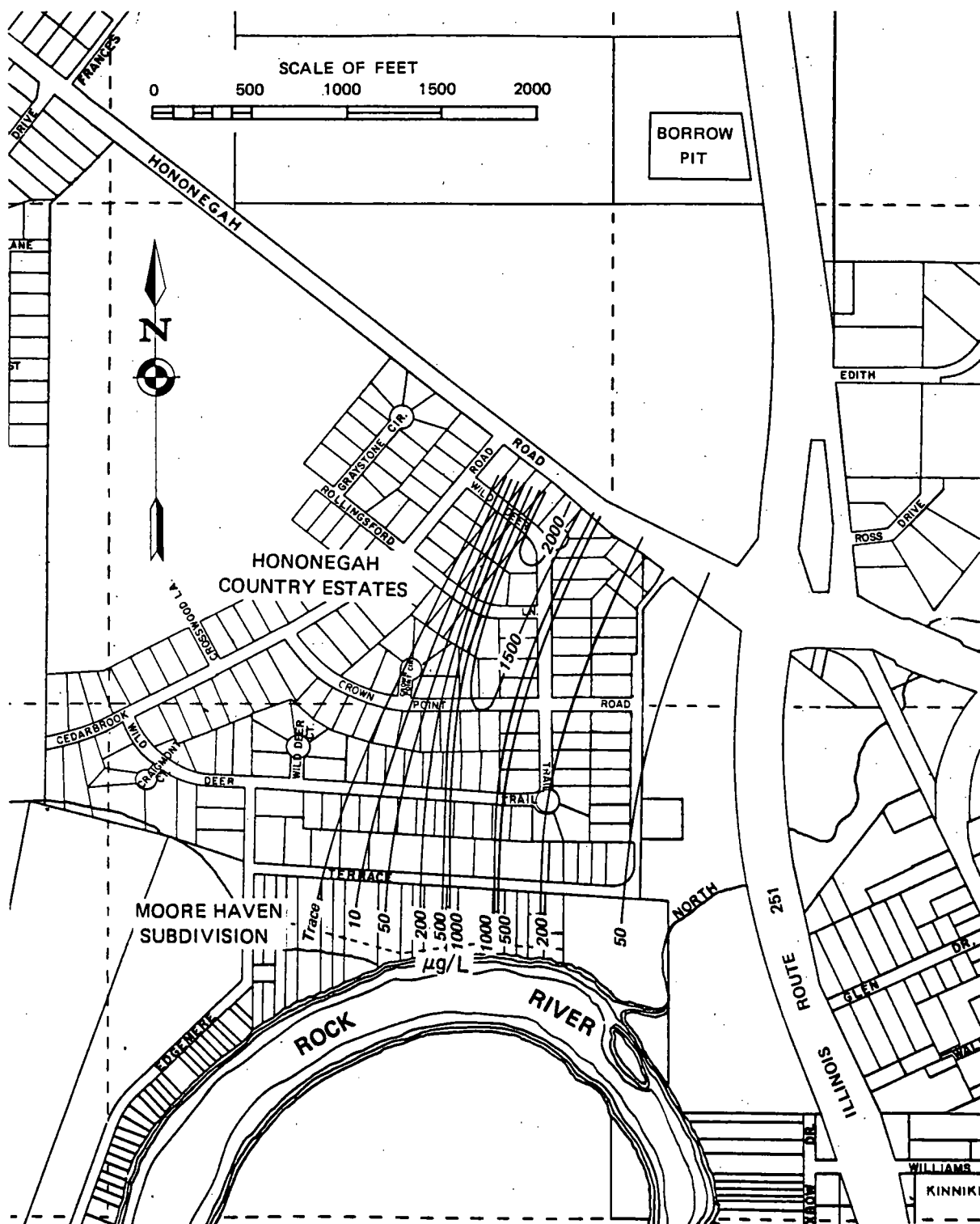


Figure 19. Contour map of TCE concentrations within Hononegah Country Estates and Moore Haven Subdivisions, January-July 1983.

delineation. Groundwater movement toward North Kinnikinnick Creek may also cause spreading of the plume along its eastern boundary. It is also possible that the plume's appearance, being ultimately related to the nature of its source, may be less distinct along its eastern boundary because of the manner in which the contaminant is introduced to the groundwater system. In other words, the plume may be the result of more than one source, for example, a point source which is producing the main body of the plume and a line source which is adding smaller amounts of contaminant over a larger area.

Another contour map of the same area, prepared from the "mass" sampling of 48 domestic wells in October 1983, is shown in figure 20. A comparison of the two TCE contour maps might suggest that the plume shrank between early and late 1983. However, the data suggest that the October map reflects the results of sampling fewer wells. Inspection of TCE concentrations in wells sampled during both periods in 1983 show no specific trend toward a decrease in TCE.

Judging by the contour maps and the time-concentration data, the plume is stable with some variation about a mean concentration for a given location within the plume. At the rate of groundwater movement, 1 foot/day, it is not likely that contaminant concentrations should vary widely over short periods of time.

Groundwater samples collected from other private wells throughout the area further clarify the extent of the VOC contaminant plume. Samples collected from five domestic wells north of McCurry Road contained no TCE and two private wells located southwest of the intersection of McCurry Road and Route 251 contained only trace levels of TCE. Specific construction details of the domestic wells are not known; depths are estimated to be between 40 and 75 feet based on well records for the area. Most of the domestic wells

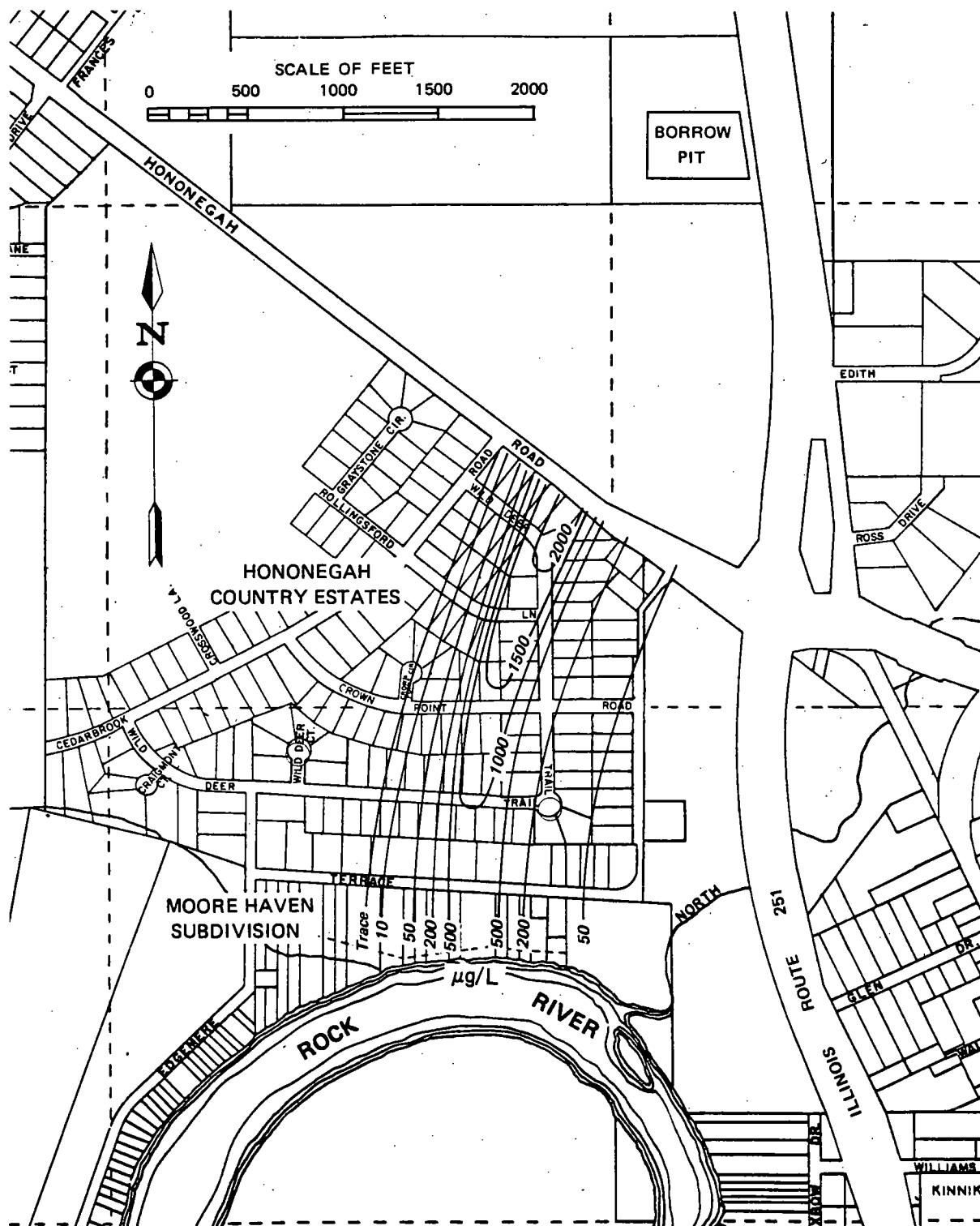


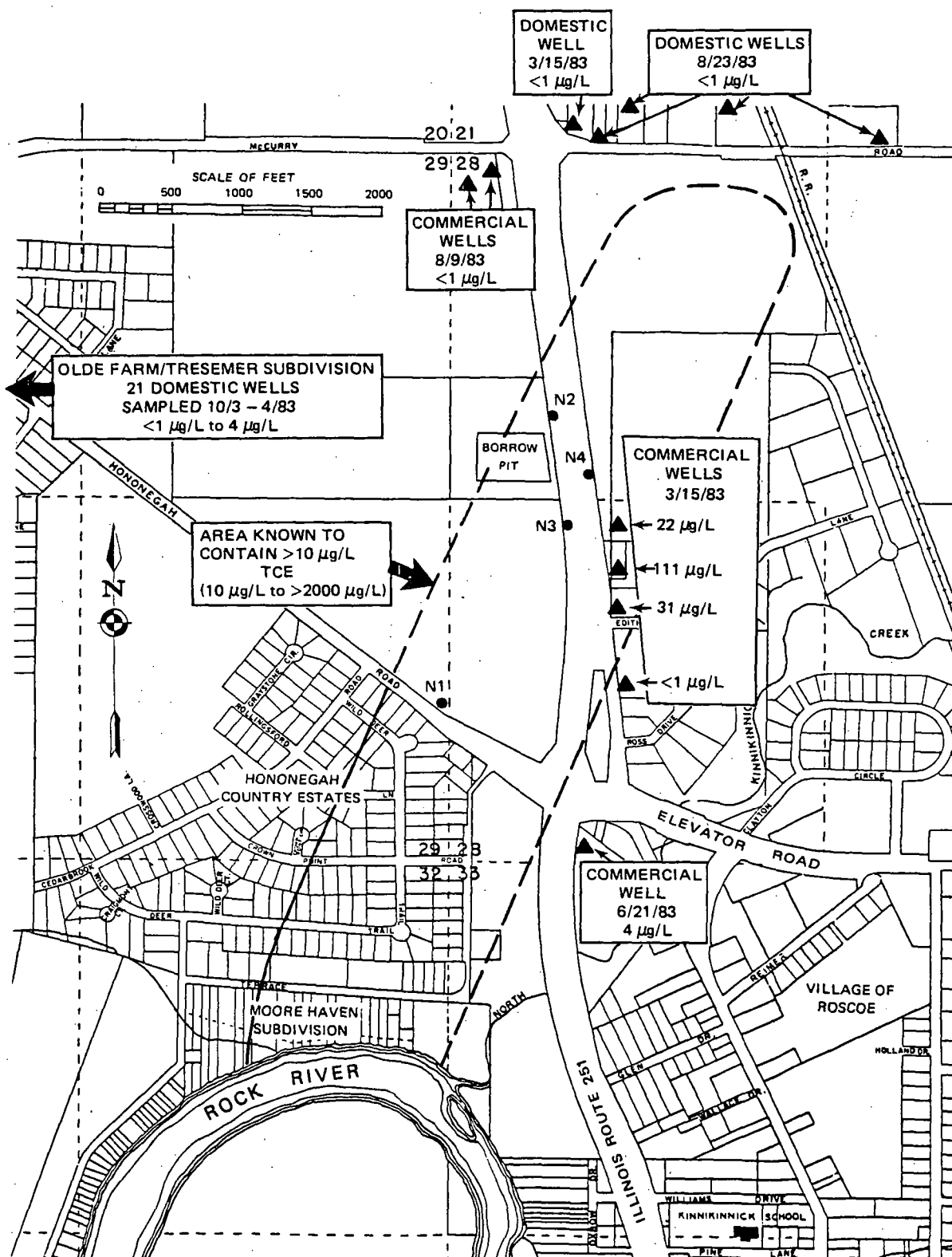
Figure 20. Contour map of TCE Concentrations within Hononegah Country Estates and Moore Haven Subdivisions, October 1983.

in the area are 65 to 75 feet deep and would be the expected depth of 4 of the 5 domestic wells sampled in this area. The fifth domestic well and one of the two private wells southwest of McCurry Road and Route 251 are known to be sand points and are probably no deeper than 40 to 45 feet. The second private well southwest of McCurry Road and Route 251 is a large capacity well completed at approximately 90 feet. Samples collected in Tresemer and Olde Farm Subdivisions, 1/2 mile west of Hononegah Country Estates, contained a maximum of 4 µg/L total VOCs and commonly had trace levels to no TCE detected.

A map summarizing the likely extent of the VOC contaminant plume is shown in figure 21. This map includes a limited amount of data from privately-owned monitoring wells located on the industrial property up-gradient of the ISWS/IEPA monitoring wells. The dashed lines indicate the probable extent of the contaminant plume based on the dimensions of the plume as it passes beneath Hononegah Country Estates and Moore Haven Subdivisions and the groundwater flow data. The sparsity of wells to sample in areas north of Hononegah Road both east and west of Route 251 do not allow exact definition of the lateral extent of the VOC contaminant plume.

Summary of Field Results

The results of well sampling and groundwater flow measurement clearly indicate the VOC contaminant plume is moving from an area upgradient of the subdivisions in a very distinct path to the Rock River. A summary of data defining the VOC plume, how that relates to the source of contamination, and the level of VOCs experienced by residents in the Hononegah Country Estates and Moore Haven Subdivisions follows:



1. a. The plume is at least 1200 feet wide as it approaches the Rock River. The western edge of the plume beneath the subdivisions is clearly discernible while the eastern edge is much less clear. Potential groundwater contribution (flow) to North Kinnikinnick Creek and an unclear picture of the VOC source combined with the lack of sampling points between Hononegah Country Estates and North Kinnikinnick Creek have not allowed a more clear definition of the eastern boundary of the VOC plume.
- b. The plume is at least 5000 feet long from a line between ISWS/IEPA Nests 2 and 4 to the Rock River along the groundwater flow path. No TCE was found in any of the domestic wells sampled north of McCurry Road indicating the plume's maximum length is no more than 7200 feet.
- c. The plume has been found to stratify and descend approximately 5 to 10 feet for every 1000 feet it moves toward the Rock River. It is believed maximum VOC concentrations occur beneath the subdivisions at 60 to 70 feet, the depth of most of the wells in that area. It does not appear that the contaminant has descended to the intake level of the wells in response to pumpage, rather the downward movement is uniform along its path and probably is the result of its density or a response to natural recharge.
2. The average hydraulic conductivity of the materials being monitored is 800 gpd/ft² (3.8×10^{-2} cm/s). For a hydraulic gradient of 0.0022 ft/ft and assuming an effective porosity of 0.25, the rate of

groundwater movement is 1 foot/day. A conservative constituent in the groundwater, one that is not chemically or biologically affected, will move at this rate also.

3. The VOC concentrations found in ISWS/IEPA Nests 2 and 4 indicate the 2-acre borrow pit located between Nests 2 and 3 along the west side of Route 251 is not the likely source of VOCs. Nest 2 is located approximately 150 feet north of the pit and Nest 4 is located nearly 200 feet east of the pit. If a contaminant was dumped or buried in the pit, leachate would move vertically downward beneath the pit until the water table was reached. Horizontal movement with the flow of groundwater to the south-southwest would then occur. For contaminant to move upgradient or transverse to the gradient as far as Nests 2 or 4, the formation of a groundwater mound, produced from the disposal of large amounts of liquid, would have been necessary. Considering the hydraulic conductivity of the sand and gravel in this area, several thousands of gallons of liquid per day would be required to create a mound of sufficient magnitude to cause groundwater flow outward from the pit to Nests 2 and 4.
4. The VOC source (or sources) must be located upgradient of the ISWS/IEPA Nests 2 and 4 and appears to be downgradient of the domestic wells sampled along McCurry Road. If the vertical migration of contaminant is uniform and recognizing the maximum contaminant concentrations descended 10 to 20 feet in the 2000 feet between ISWS/IEPA Nests 4 and 1, then 2000 feet upgradient of Nest 4 should place the contaminant 10 to 20 feet above the depths found at

- Nest 4. This would place the contaminant very near the top of the saturated zone (the water table) and directly beneath the potential source(s).
5. At the rate of groundwater movement, 1 foot/day, it takes approximately 8 years to move the 2800 feet from Nest 1 to the Rock River. Therefore, the plume beneath Hononegah Country Estates and Moore Haven Subdivisions gives a history of at least eight years of groundwater contamination. The continuity of the plume indicates the source has been continuous and of fairly constant strength.
 6. Without information to pinpoint when the leading edge of the plume first reached the Rock River, it is impossible to determine exactly when the contamination originated. Because the plume is 5000 to 7200 feet long and based on a rate of movement of 1 foot/day, contaminants presently reaching the Rock River must have been introduced to the groundwater system 14 to 20 years ago.
 7. Given the available information, there are two scenarios which should be examined to define the degree to which residents have been exposed:
 - a. Assume the leading edge of the plume has only recently reached the Rock River. Therefore, people living in the subdivisions have not been receiving a constant dose but a dose slowly increasing to the present concentrations. This means those persons living closest to the river have been ingesting contaminated water for only the past year or so. This scenario would give the overall least exposure for a given location within the plume.

- b. Assume the plume has been discharging to the Rock River for several years. Therefore, due to the relatively young age of the homes in the subdivisions (less than 10 years for most homes), the groundwater has been contaminated at presently observed concentrations since the homes were originally built. This scenario describes a steady state condition and gives the greatest possible exposure.

COMPUTER MODELING OF THE VOC PLUME

To further analyze the field data, a "random-walk" solute transport code²⁸ was used to simulate the organic contaminant movement through the aquifer. Output generated by the computer model provided the time-concentration relationships needed to calculate the potential VOC doses residents may have ingested. The modeling procedure also gave insight on the location and strength of potential contaminant sources.

Model Preparation

The two-dimensional finite difference grid of the model overlain on topographic features was shown in figure 12. The grid was arranged in a 15 by 41 array with a uniform nodal spacing of 200 feet. Because the groundwater elevation contours shown in figures 13-16 showed no effect from groundwater pumpage, no head calculations were performed by the model. Instead, a uniform flow field with a velocity of 1 foot per day in the direction of increasing row (j) values was entered directly into the computer code. An adjustment was made to the direction of the velocity vector to simulate the observed bending of the groundwater flow path as the Rock River was approached. A best fit to observed conditions was achieved when the velocity vector was incremented by 5 degrees (in the increasing i-direction) starting in row 27 and proceeding with every other row until the Rock River nodes were encountered in rows 37 and 38. Therefore, the velocity vector at row 37 rather than being 1 foot/day in the j-direction, was 1 foot/day oriented 20 degrees from the j-direction. Sink nodes were placed in rows 37 through 41 to simulate groundwater discharge to the Rock River. All mass movement occurred between the source and sinks in the model interior.

The computer model simulates solute concentrations evenly distributed over the entire saturated thickness of the aquifer. It cannot simulate the effect of density-induced or recharge-induced convection (stratification) that was noticed in the field data. To compensate for this deficiency, the thickness of the "aquifer" in the model was defined to be twenty feet, an approximation of the thickness of the contaminated zone. The model assumes that the aquifer is horizontal which, for the purpose of this study is reasonable.

For this study, no attenuation of the VOCs, other than natural ground-water dilution, was considered. The low organic content of the sand and gravel aquifer should create little significant retardation of contaminant movement. Potential volatilization of the VOCs into the unsaturated zone also was not considered.

Model Simulation

Parameters governing the source locations, source strength, transverse dispersivity, and longitudinal dispersivity were adjusted through trial simulations to calibrate the model to observed conditions. The plume dimensions and TCE concentrations that were observed beneath Hononegah Country Estates and Moore Haven Subdivisions were used primarily to compare against simulated conditions. Data collected at the ISWS/IEPA monitoring wells served for additional comparison.

To achieve the desired resolution of spatial concentration changes, 200 particles were released randomly during each 2-year iteration for a 30 year simulation. Each particle represented approximately 64 $\mu\text{g/L}$ TCE. Several

source locations were simulated; the best fit to the observed plume was produced when the particles were released from a point source located at node $(i,j) = (5,7)$.

Model calibration was completed by adjusting the dispersivity (spread) of the contaminant plume as it moved through the model aquifer. A value of 3.0 feet for the transverse dispersivity best reproduced the spread of the plume perpendicular to the direction of groundwater movement. No data were available to calibrate the longitudinal dispersivity, the spread of the plume in the direction of groundwater flow. Trial simulations using longitudinal dispersivities up to 15.0 feet (five times the transverse dispersivity) produced little appreciable change in contaminant arrival times at down-gradient locations. For this study, a longitudinal dispersivity of 6.0 feet was used.

Model Output

Figure 22 is a typical printout of the model grid showing TCE concentrations within model nodal areas (half of a grid either side of a specified node) for a given simulation iteration. This printout represents the plume configuration after 22 years of simulated solute transport from the continuous point source. The solute particles were introduced to the system at node (5,7), which simulates a source approximately 1600 feet upgradient of ISWS/IEPA monitoring nest 4.

The central axis of the plume followed column 5 until row 30 when the plume became diagonally orientated. The change in direction results from the changes in velocity vectors previously described. Nodes depicted by an "R" represent the north bank of the Rock River and were delimited as sinks where solute particles would "discharge" and leave the system.

THERE ARE 1736 PARTICLES IN THE SYSTEM EACH WITH A MASS OF .80 POUNDS
MAP SHOWING CONCENTRATION IN PPB AT TIME= 22.00 YEARS

		COLUMN NUMBER (I)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	7	0.	0.	0.	0.	1923.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	8	0.	0.	0.	0.	3269.	64.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	9	0.	0.	0.	0.	3526.	64.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	10	0.	0.	0.	64.	3590.	385.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	11	0.	0.	0.	192.	2500.	192.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	12	0.	0.	0.	256.	3013.	192.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	13	0.	0.	0.	321.	2692.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.
R	14	0.	0.	0.	769.	2885.	385.	0.	0.	0.	0.	0.	0.	0.	0.	0.
O	15	0.	0.	0.	833.	2115.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W	16	0.	0.	64.	897.	1923.	577.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	17	0.	0.	0.	897.	2179.	962.	0.	0.	0.	0.	0.	0.	0.	0.	0.
N	18	0.	0.	64.	513.	1795.	577.	0.	0.	0.	0.	0.	0.	0.	0.	0.
U	19	0.	0.	0.	513.	1923.	577.	0.	0.	0.	0.	0.	0.	0.	0.	0.
M	20	0.	0.	64.	641.	2115.	321.	0.	0.	0.	0.	0.	0.	0.	0.	0.
B	21	0.	0.	128.	1026.	1795.	833.	64.	0.	0.	0.	0.	0.	0.	0.	0.
E	22	0.	0.	0.	641.	2500.	897.	64.	0.	0.	0.	0.	0.	0.	0.	0.
R	23	0.	0.	128.	769.	1731.	577.	64.	0.	0.	0.	0.	0.	0.	0.	0.
	24	0.	0.	128.	897.	2051.	385.	0.	0.	0.	0.	0.	0.	0.	0.	0.
(J)	25	0.	64.	0.	1218.	1859.	897.	256.	0.	0.	0.	0.	0.	0.	0.	0.
	26	0.	0.	128.	449.	1474.	769.	64.	0.	0.	0.	0.	0.	0.	0.	0.
	27	0.	0.	128.	577.	1667.	577.	192.	0.	0.	0.	0.	0.	0.	0.	0.
	28	0.	0.	0.	833.	2051.	1410.	128.	0.	0.	0.	0.	0.	0.	0.	0.
	29	0.	0.	64.	321.	1795.	962.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	30	0.	0.	0.	705.	1667.	1346.	192.	0.	0.	0.	0.	0.	0.	0.	0.
	31	0.	0.	0.	321.	1218.	1026.	513.	0.	0.	0.	0.	0.	0.	0.	0.
	32	0.	0.	0.	64.	962.	1859.	769.	64.	0.	0.	0.	0.	0.	0.	0.
	33	0.	0.	0.	64.	833.	897.	1026.	128.	0.	0.	0.	0.	0.	0.	0.
	34	0.	0.	0.	0.	321.	1346.	1538.	705.	0.	0.	0.	0.	0.	0.	0.
	35	0.	0.	0.	0.	449.	1026.	1218.	1026.	321.	0.	0.	0.	0.	0.	0.
	36	0.	0.	0.	0.	0.	321.	1923.	1859.	449.	64.	0.	0.	0.	0.	0.
	37	0.	0.	0.	0.	0.	128.	1346.	1795.	833.	R	R	R	R	R	0.
	38	0.	0.	0.	0.	0.	192.	641.	897.	R	R	0.	0.	0.	R	R
	39	0.	0.	0.	0.	0.	0.	R	R	R	0.	0.	0.	0.	0.	0.
	40	0.	0.	0.	0.	0.	0.	R	0.	0.	0.	0.	0.	0.	0.	0.
	41	0.	0.	0.	0.	0.	R	0.	0.	0.	0.	0.	0.	0.	0.	0.

R denotes a river sink node

Figure 22. Simulated TCE plume after 22 years.

Because of the assumptions made concerning a uniform flow field, the model produced a symmetric plume. The model, therefore, does not duplicate the spreading phenomenon noticed along the eastern edge of the actual plume. As previously mentioned, groundwater movement toward Kinnikinnick Creek or from another less distinct VOC source, may be responsible for this "smearing" effect. This problem will limit the model's potential for determining the "least case" VOC exposure (Scenario One in next section) residents located at the north end of Edgemere Terrace may have experienced.

Figures 23 and 24 show TCE concentrations versus time for four nodal areas within the simulated plume. These nodes were chosen to illustrate the temporal and spatial relationships of locations within the plume. The uneven distribution of the simulated concentrations is a function of the mass of the prescribed particles and the time increments over which the particles are moved. Using more costly simulations, the simulated concentrations would approach the displayed asymptotic concentration curves.

The time period over which contaminants begin to appear and the concentrations which are attained at the different locations is particularly important to the epidemiological investigation. For example, at node (5,29), TCE concentrations begin to increase after the tenth year of simulation (figure 23). Appreciable TCE concentrations are not seen at node (9,36) until four years later. Node (5,29) is closer to the central axis of the plume and experiences a steady-state concentration approximately 1100 $\mu\text{g/L}$ greater than that node (9,36) which is located along the eastern boundary of the plume. Similar variations in concentrations for nodes (7,34) and (7,30) are shown in figure 24.

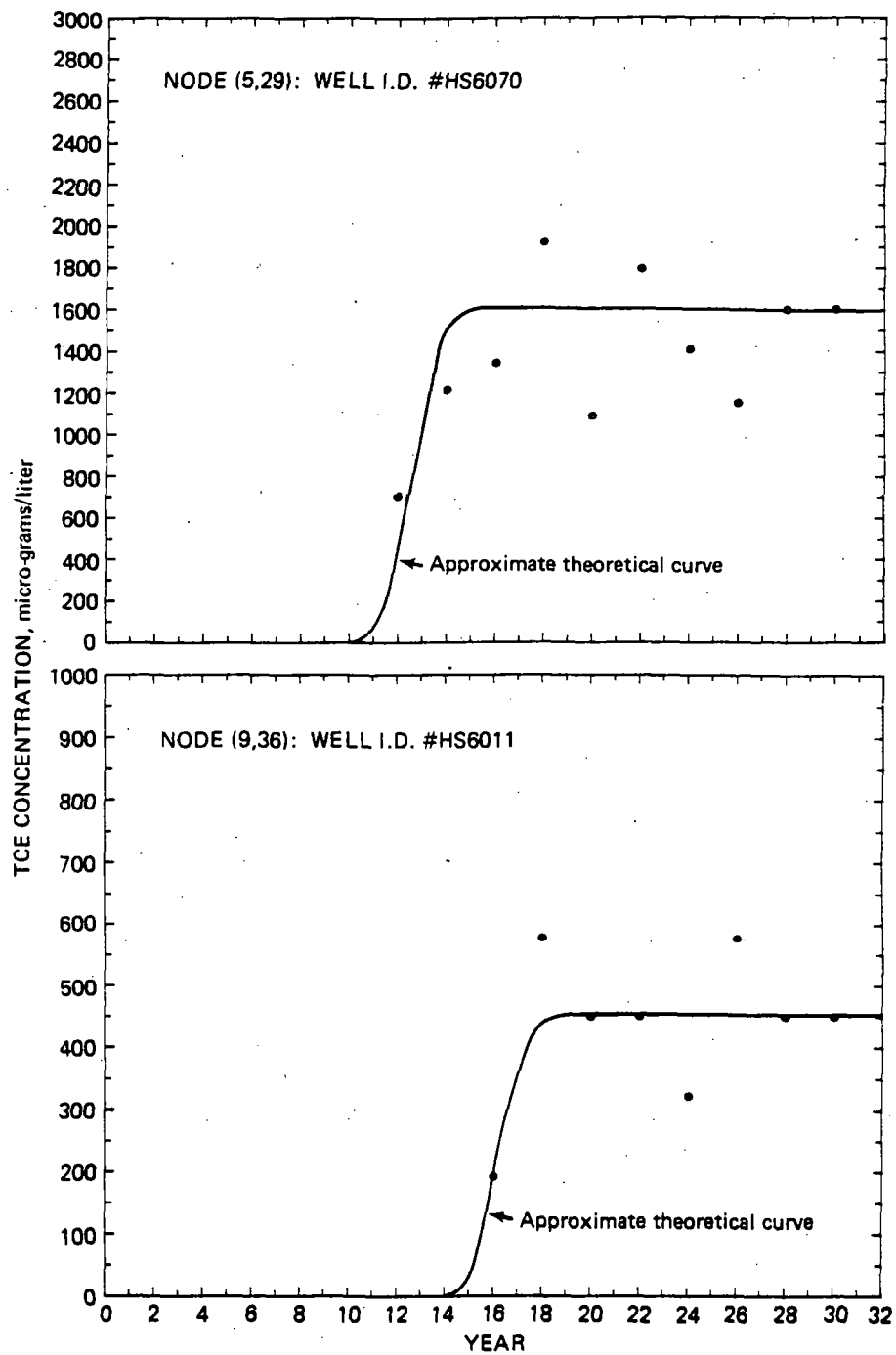


Figure 23. Simulated TCE concentrations at nodes (5,29) and (9,36).

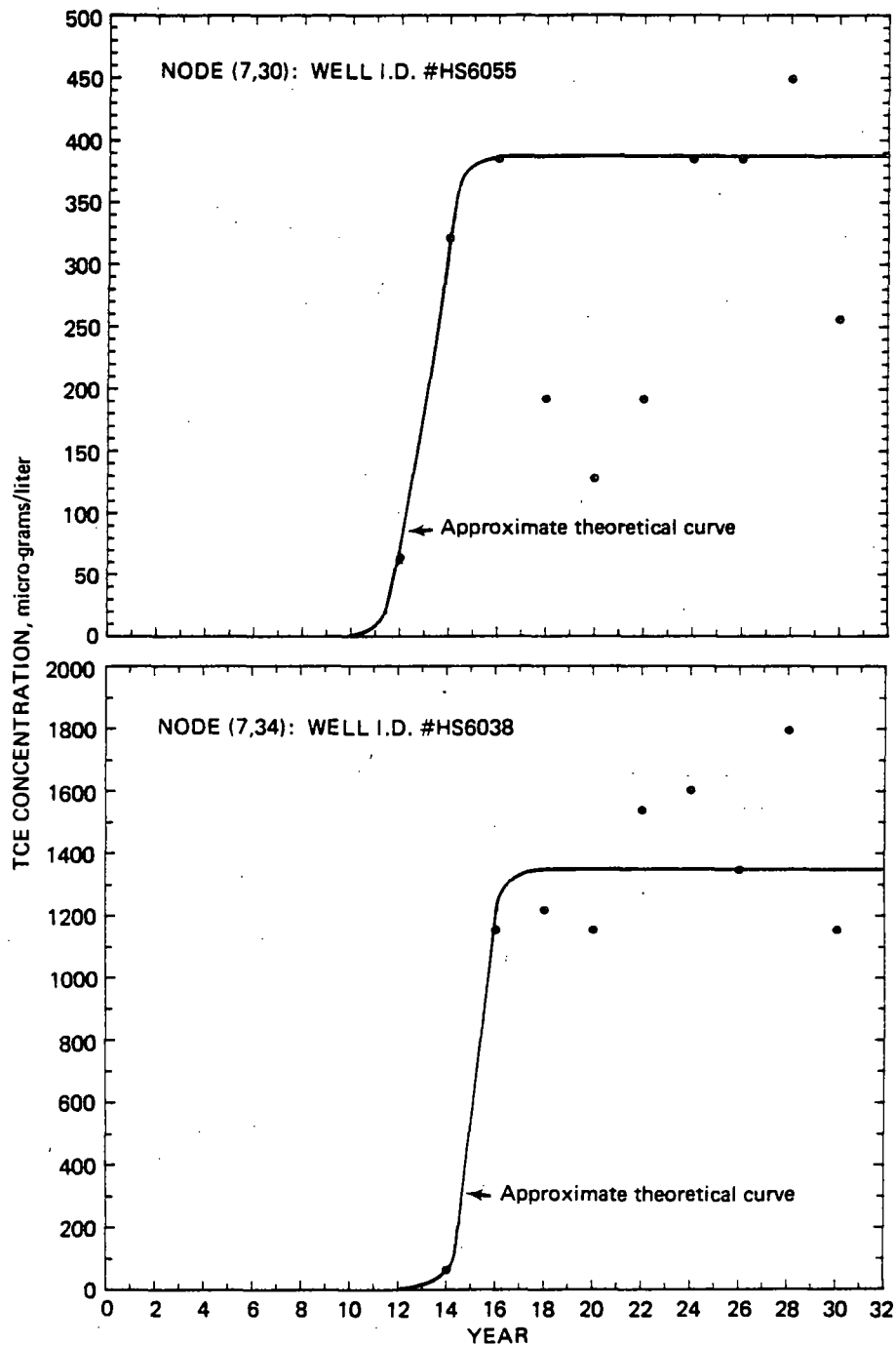


Figure 24. Simulated TCE concentrations at nodes (7,30) and (7,34).

Potential VOC Ingestion

As previously mentioned, these graphs can be used to evaluate the amount of TCE ingested by residents living within the affected subdivisions. Two scenarios are described to place a range on the estimated doses.

For Scenario 1, the leading edge of the plume was assumed to have just recently reached the Rock River. A well located near the river would have become contaminated only within the past year. A well near node (9,36), HS6011, located along Edgemere Terrace, is one of the wells closest to the Rock River. The model simulation showed TCE concentrations began rising at this node between Year 14 and 16 (figure 23). If Year 15 is assumed to be 1983, then the length of time and the concentrations experienced at other locations can be determined using Year 15 as 1983.

An estimate of the ingested TCE dose can be calculated by determining the area under the TCE concentration graph for the period of time in which a subject was in residence and multiplying that area by an estimate of the total water intake over the period of exposure. An average daily intake of water was assumed to be 2 liters. For most of the homes in the subdivisions, this calculation involved the "rising limb" of the time-concentration graph. As previously mentioned, for some homes located at the north end of Edgemere Terrace, the model did not simulate observed conditions and calculations for this scenario could not be done. Sample calculations of the total potential TCE ingested for the wells graphed in figures 23 and 24 under Scenario One are shown in Table 7. It is important to note that the simulated plume has been present at the location of wells HS 6055 and HS 6070 longer than the residents have reported to be living within the area. In this situation, the total area beneath the graph is not used but only that portion which would

include the length of time a subject has lived at that location. Volatilization of TCE between the well and faucet was assumed to be negligible. More refined estimates of water intake and TCE losses may be used by the epidemiological study investigators.

For Scenario 2, it was assumed that the plume has been discharging to the Rock River for several years, long enough that the recently observed TCE concentrations were also present when the homes were built approximately ten years ago. It can then be assumed that presently observed TCE concentrations have been ingested for the total length of residence at any particular location. The total TCE ingested would then be the product of the presently observed concentration, the length of residence, and the total water intake over the residence period. Sample calculations of the total TCE ingested under Scenario Two are also shown in Table 7. For the purposes of these sample calculations, average TCE concentrations for each well were estimated as the asymptotic values approached by the model as described by the curves on figures 23 and 24. Due to differences between the simulated and observed TCE concentrations particularly along the eastern edge of the "smeared" plume, it would be best to use observed concentrations.

Table 7. Sample Calculations of Total TCE Ingested
Under Scenarios 1 and 2

Scenario 1

Well I.D.	Simulated yr of TCE discovery	Potential years of exposure	Years in residence ^a	Area under graph (fig.23) ($\mu\text{g/L-yr}$)	Total TCE ingested (mg) ^b
HS 6011	15 ^c	1	23	15	11
HS 6038	13	3	4	453	330
HS 6055	11	5	3	1105	810
HS 6070	11	5	4	4465	3260

Scenario 2

Well I.D.	No. of years in residence	Average TCE concentration ($\mu\text{g/L}$)	Total TCE ingested (mg) ^b
HS 6011	23 ^d	449	3280
HS 6038	4	1346	3930
HS 6055	3	385	840
HS 6070	4	1603	4680

a) As reported to the Winnebago County Public Health Department

b) Assumed an average daily water intake of 2L

c) HS 6011 is well nearest the Rock River; Scenario 1 is based on the assumption that this well became contaminated within the past year. All other wells use Year 15 from which to count potential years of exposure.

d) Assumed a maximum of 10 years exposure

CONCLUSIONS AND RECOMMENDATIONS

During the winter of 1983, the Winnebago County Public Health Department instituted a sampling effort to examine for the presence of organic constituents in the groundwater of a small area in northern Winnebago County. An initial sampling at 5 homes in January and February found volatile organic chemicals ranging from 60 to over 1000 $\mu\text{g/L}$. The principal component found in all samples was trichloroethylene, a widely used industrial solvent. Through the following year, work concentrated on delineating the extent of the VOC plume and its movement and estimating the exposure to VOCs that local residents may have received from their drinking water.

The VOC plume has been determined to be approximately 6000 feet long oriented in a north-northeast to south-southwest direction. Beneath the two affected residential areas, Hononegah Country Estates and Moore Haven Subdivisions, the plume has spread to about 1200 feet in width. TCE concentrations range from trace amounts along the western edge of the plume to over 1500 $\mu\text{g/L}$ along the central axis of the plume.

The plume was found to have stratified within the aquifer and is descending 5 to 10 feet for every 1000 feet it moves toward the Rock River. Maximum VOC concentrations were detected in a zone approximately 20 feet thick, occurring at a depth between 60 and 80 feet, the depth of most of the wells in the affected subdivisions. Hydraulic conductivity testing and mapping of groundwater elevation contours indicate that the rate of groundwater movement is approximately 1 foot per day toward the Rock River.

The data indicate the VOC plume crosses beneath Route 251 between ISWS/IEPA monitoring well nests 2 and 4. Based on both the vertical and horizontal migration patterns of the plume, the VOC source must be in the vicinity of a local industry. Historic anecdotal data are not available to

substantiate the specific cause of contamination. At the rate of contaminant movement, estimated to be equal to the groundwater flow rate (1 foot per day), the source may have originated as long as 20 years ago.

Based on available data and computer simulation of contaminant movement, two scenarios were employed to bracket a range of possible TCE doses that residents of the area may have experienced. TCE doses were determined by calculating the area under a simulated curve of TCE concentration versus time and multiplying the area by an estimate of total water intake. In determining a "least" case, the leading edge of the plume was assumed to have just recently reached the Rock River. A "worst" case scenario was determined by assuming that the plume has been discharging to the Rock River long enough that presently observed concentrations of TCE would have been present since the time most of the homes were built.

Calculations based on the modeled transport of contaminant through the aquifer indicate approximately 10 gallons of contaminant per year (0.03 gallons per day) has been released to the groundwater system. Similar calculations, based on the total number of particles used to simulate the TCE plume, indicate approximately 170 gallons of TCE is distributed throughout the zone of contamination. Without further investigation, it is impossible to determine the exact nature of the source. It is recommended that monitoring of the ISWS/IEPA wells be continued to determine if mitigation measures taken by the industry have been effective in abating the VOC plume.

The relatively small volume of contaminant involved, the size of the resulting plume, and the resulting exposure of residents in the area to TCE, illustrate the importance of exercising extreme caution in the protection of groundwater from hazardous materials. Several previous investigations have documented the susceptibility of the groundwater in this part of northern

Winnebago County to potential contamination.^{1,10,16,29} The most recent study²⁹ categorized the general Roscoe area as a low priority area for having potential hazardous waste problems compared to other areas in Winnebago County. A low potential risk rating was assigned to this area because of the low population-at-risk and the low number of local generators or handlers of hazardous materials. The discovery of the organic plume in an area assigned a low priority emphasizes even more the need for increased awareness and action in areas delineated for higher priority.

The experience gained from this study points out the potential for improved scientific investigations that cooperation between the regulating agencies, the regulated community, researchers, and an involved public can provide. In many aspects, the collection and exchange of useful information was greatly enhanced. Certainly, much better and quicker resolution of problems and solutions can be discussed so the most useful information can be collected.

However, the potential for liability in groundwater contamination cases will always create difficulties which can inhibit the collection or exchange of important data (a potential defendant is not likely to provide information that may be detrimental to his case). Incentives for providing information, such as generally quicker and less expensive out-of-court settlements, might produce more cooperativeness. The regulated community must be encouraged to cooperate because questions concerning such basic information as source identification, for example, must be pursued if clear solutions are to be made.

As more groundwater contamination situations arise, issues of public health, contaminant source identification, abatement, and groundwater quality rehabilitation will also increase. Improvements must be made at the state and local levels if accurate and timely environmental judgments are to be

made. In particular, state-of-the-art sampling equipment and lab facilities (and the trained personnel to man them) are essential if regulatory authorities are to be expected to deal with a new era of exotic organic chemicals.

The discovery of this organic contaminant was indeed fortunate. Domestic wells are not routinely sampled to determine the suitability of the water they produce for human consumption. Even when sampled, the water is not normally analyzed for organic constituents (a costly procedure). The manner in which this plume was discovered illustrates the need for a comprehensive plan for routine sampling of private wells throughout the state, particularly in locations downgradient of potential groundwater contamination sources.

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